
Design and Fabrication of the NASA HL-20 Full Scale Research Model

by

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ABSTRACT

A full-scale engineering model of the HL-20 Personnel Launch System (PLS) was constructed for systems and human factors evaluation. Construction techniques were developed to enable the vehicle to be constructed with a minimum of time and cost. This report describes the design and construction of the vehicle.

Introduction

One of the primary, near-term objectives of the national space program is to deploy a manned space station into low earth orbit. This dictates the need for frequent and reliable access to space to deliver the required personnel and payload. Much of this responsibility was to be carried by the existing Space Shuttle fleet. However, more emphasis is now being placed on an alternate space transportation system which could meet the demands with greater cost-effectiveness, improved operations, and more safety than the Shuttle.

One of the concepts that has been under study by NASA to place people and small payloads into orbit is referred to as the Personnel Launch System (PLS). Its primary role is to provide a ten man crew rotation link between earth and Space Station Freedom within a three day total mission duration window. Many of the lessons learned during the Shuttle program are being applied to the design of the PLS in an effort to increase reliability and safety to a level necessary to meet its long term objectives.

Two PLS configurations are currently being considered. One is a biconic shaped capsule which is being investigated by NASA Johnson Space Center and the second is a lifting body design which is being studied at NASA Langley Research Center. The relative benefits and disadvantages of each are being carefully examined in an effort to converge on a preferred concept which could then be further developed as funding becomes available. This report pertains to work which was performed in support of the NASA Langley lifting body design effort and thus will further concentrate on this particular configuration.

A lifting body concept is well suited to the role of the PLS because of it provides controllability throughout a wide range of Mach numbers, good cross-range capability, and the ability to utilize existing runways for conventional wheeled landings.

Extensive lifting body research of the 1960's and 1970's identified the traits of such

vehicles and provided the basis for the current design. Many hours of wind tunnel testing and computational investigations at NASA Langley have led to the evolution of a promising configuration which has since been designated "HL-20." The general characteristics of the HL-20 are depicted in Figure 1. The small size of the vehicle was actually the result of a design constraint that it fit entirely within the payload bay of the existing Shuttle. The result is a significant packaging problem which could possibly compromise the ergonomic needs of the crew and passengers. In order to carefully address these human factors issues, NASA Langley funded the Mars Mission Research Center at North Carolina State University and North Carolina A&T State University to construct a full scale research model of the HL-20. A list of faculty and student participants is given in Appendix A.

The research objectives of the HL-20 model (see Appendix B) specified that it must be capable of accommodating a full crew in both horizontal (runway) and vertical (launch) attitudes. This not only defined the structural requirements of the vehicle, but also dictated the need for an accompanying model support structure. The project was therefore organized to utilize the resources of North Carolina State University to design and construct the PLS model and those of North Carolina A&T State University to fabricate the articulating support structure. Scheduled meetings between NASA and the two universities insured that the necessary requirements were accommodated and insured proper interface of the two components.

This report documents the structural design and innovative fabrication procedure utilized to construct the PLS research model within an unusually short time frame and a modest budget.

FABRICATION

General Design Approach

The schedule constraints established at the beginning of the project were the driving force behind the entire design process. The actual construction was to begin in late March 1990, and the vehicle was to be rolled out in mid September of the same year. This schedule also included the start-up of a new shop facility and procurement of equipment and materials. North Carolina State University undergraduate engineering students were the sole source of labor, so full-time workers were available only during the summer. The bulk of the construction, then, had to be performed during those three months.

The strict time requirements would not permit the usual molding technique of building a male mold and then, from that shape, forming a rigid female mold. Another common prototyping technique in which the composite skins are formed over a solid foam core could not be used due to the requirement for an open interior volume and removable panels. Instead, the male tool, or plug, stage was eliminated altogether and expendable polystyrene female molds were made directly from the NASA LaRC supplied data. Using this method, molds for large sections of the vehicle could be built in a matter of days. Parts were laid up in these molds with integral flanges for attaching them to adjacent parts. The internal structure consisting of bulkheads, longerons, and local skin stiffeners were added to the skins while still in the molds. All molds were destroyed as the parts were removed. Parts were assembled with bolts through the flanges to aid in future disassembly. The parting lines between the sections of the vehicle shell are shown in Figure 2.

Geometric Manipulation and Laser Cut Templates

Approximately 250 fuselage station cuts for a total of 90,000 data points were transferred from the NASA lofting files. Rather than make templates for each of these sections, an error analysis was done to select the minimum number of station required for a maximum of a 0.1 inch error in the contour (Figure 3a). Eventually, it was found that the vehicle could be defined with the 48 cross sections shown in Figure 3b. The thickness of the individual sections ranged from 2.5 inches near the front of the vehicle where the contour changes rapidly to 15 inches at the tail. Table 1 lists the fuselage stations of the templates.

The data were converted from the NASA .LWG file to ACSII format and transferred to an Autocad 3-D drawing. Each station was modified in Autocad 2-D to prepare it for laser cutting. Each section was divided into quarters along the proper planes as shown in Figure 4a. Other modifications included fuselage station identifiers, joggles for flush fitting exterior tapes, and equally spaced marks along the contour line to serve as an aid in later hotwiring (Figure 4b). A Smartcam post processor optimized the geometry for the laser cutter. Templates were then laser cut from 48-inch by 96-inch sheets of 1/8-inch-thick Masonite.

Generic Mold Fabrication Technique

The 1.5 pound per cubic foot expanded bead polystyrene foam was purchased in 96-inch by 48-inch by 12-inch blocks. Each section had to be custom cut to the correct thickness. This was done by placing the block on a large flat table and sliding it along lengthwise through a electrically heated horizontal wire set at the proper vertical position (Figure 5). The two Masonite templates that defined a given section were then positioned on either side of the foam and a hotwire was passed along the template edges as shown in Figure 6. Equally spaced marks previously laser cut into

each template along the contour surface helped keep the hotwire in the same relative position on both sides of the foam.

After all the foam sections for a given mold were cut, they were assembled on a flat surface. Reference lines were drawn along the surface to keep the mold straight as sections were added. The foam sections were bonded to one another using foam adhesive dispensed from a caulking gun as shown in Figure 7. In the case of the heatshield, the sections were also bonded to the floor, since in this case the mold also served as an assembly fixture for the entire vehicle. Some light sanding was done at this point to reduce future contour work. Particle board dams were bonded or clamped along the edges of the mold where mating flanges were to be formed.

Generic Part Layup Technique

The epoxy system used throughout the HL-20 model was Apco 2410 resin with 2183 hardener. This system cures at room temperature in approximately 24 hours. A large layup were performed with brushes, squeegees, and rollers can be seen in Figure 8.

After mold preparation was complete, the mold was covered with a layer of light weight Dacron cloth, or peel ply, which was wetted out with epoxy. Next carbon roving (approximately .05 inches²) was wetted in an epoxy bath and packed into the tight corners along the flanges. The carbon roving served a double function of creating a durable edge along the flange while simplifying the task of laying up the skin into a tight radius. Five plies of 18-ounce woven E-glass roving were then laid up over the entire mold surface on a 45-degree orientation, creating a skin approximately .15 inches thick. To reinforce the mating flange areas an additional 3 plies were added, also on a 45-degree orientation, which formed a .24-inch thick flange. After all structural plies were in place another layer of peel ply was wetted out on the interior surface.

Figure 9 shows a large part being removed from its mold after a hotwire had been passed along the part surface. After removal, the remaining foam was removed from the part chisels and scrapers. The last of the foam was removed by stripping the outer peel ply layer from the part, which left a fine, fabric-like texture on the finished part. The interior peel ply was left in place to protect the surface while construction continued, then removed near project completion.

Heatshield

The right half of the heatshield was the first major body section produced. The details of the mold are shown in figure 10. A level floor was built from polystyrene foam and particle board. The foam sections were assembled and bonded to the floor. A landing gear door was laid up with five plies of the 18-ounce cloth and placed in the proper position in the mold. After cure the door was removed and trimmed, then released and placed back in the mold. The door would form a joggle in the skins that would later be used to tie the main gear box panels to the skin. The door itself was later thickened and attached to the gear well side to simulate a gear door. The nose gear box mold was made of particle board and attached rigidly to the mold. The aft end of the vehicle was formed by a large plywood dam, onto which the aft hatch was attached. Laying up the skins onto the flange of the hatch formed a flush joggle that fit the hatch exactly. The flanges that defined the top of the heat shield were formed with a particle board dam. The completed right heatshield skin is shown in Figure 11 after removal of the upper flange dam.

The left heatshield mold was built next to the right skin. As it was laid up, the plies were allowed to lap onto the right heatshield skins, forming a lap joint. Four additional plies were added to the outside of the skins in a preformed joggle along the centerline after the vehicle was on its landing gear.

As previously mentioned, the heatshield mold served as an assembly fixture for the entire vehicle. The foam was not removed until all body sections had been attached and the landing gear bolted on. The foam was removed by passing a long hotwire along the entire length of the vehicle.

Cockpit

The cockpit section was small enough that it could be formed in one continuous skin with no discontinuity at the centerline. This was fortunate in that it allowed the windshield area to be molded in one piece. The loft lines supplied by NASA LaRC did not define the windshield area with flat areas for the individual windows. Instead we were supplied with window template geometry and coordinates of their installed positions. A light fiberglass skin was laid up in the cockpit mold in the location of the windshield to provide a working surface to modify the mold to accept the flat windows. Masonite patterns of the five individual windows were made and bonded into the mold at the proper locations. The gaps beneath and between the Masonite panels were filled with expanded polyurethane foam and plaster. The filler was blended into the existing contour as smoothly as possible. When the mold was complete the actual 3/8-inch acrylic windows were released and positioned in the mold as shown in Figure 12. The layup for the cockpit area was done over the windows, forming a perfectly matched indentation for the windows. A slight bevel had been machined into the edges of the windows to insure that they could be released after layup. The windows were eventually reinstalled with a silicone bond and small screws into the laminate (Figure 13).

Flanges were formed along the lower and forward edges of the cockpit section with particle board dams. The aft end of the section was left unflanged to allow it to be matched to the center section exactly. Figure 14 shows the cockpit section being positioned on the heatshield.

Center Body Section

The center section of the upper vehicle shell was formed in two halves split at the centerline. The hatch was also formed in two sections and not joined until the left and right center sections were in place on the vehicle. The hatch halves were laid up, trimmed, and placed back in the mold prior to the skin layup to form integral joggles for a flush hatch fit as shown in Figure 15. Eventually the hatch and its supporting flange were stiffened with ten pound per cubic foot polyurethane foam covered with three plies nine ounce E-glass bidirectional cloth. The hatch was attached with 3/16-inch flat head screws engaged in nutplates riveted to the flange. Flanges were formed at all edges of the center body section except at the centerline, where a preformed joggle allowed the addition of flush fitting exterior fiberglass plies (three plies 18-ounce on a 45 degree orientation). The same layup was repeated on the interior surface. Figure 16 shows the center section as it was placed in position on the heatshield.

Aft Body Section

The upper aft section of the HL-20 shell was formed in two halves split at the centerline. The two were joined on assembly in the same manner as the center section. The acute intersection of the fins and the upper body surface prevented the layup of a continuous fiberglass skin. Instead, a dam was placed in the mold and a flange formed at the intersection. The wing fillet area and the remainder of the aft section, then, were formed in two separate layups and joined by a bolted flange. Unlike the other flanges on the vehicle, however, this flange was bonded together as well as bolted. Rectangular slots for wing attachment were molded into the aft sections by laying the part up onto a foam mockup of the wing tongue.

The aft ends of the parts were left unflanged while in the mold. The two halves of the aft body section were jigged in place and installed on the vehicle. The aft end of the vehicle was laid up from the inside of the vehicle unto a large plywood dam. The

layup lapped onto the door and onto the panel that had been formed at the aft end of the heatshield to complete the aft plane of the vehicle. The right aft section is positioned on the heatshield assembly in Figure 17.

Nosebowl

The nosebowl of the HL-20 changed in cross section so rapidly that the foam female method of tooling would have been difficult. Therefore the forward 17.68 inches of the vehicle were shaped using male templates to form a polystyrene foam plug of the nose (Figure 18). A ring of 3/4-inch plywood formed the aft mounting plane of the nosebowl. The nose was shaped and covered with two plies of 9-ounce E-glass cloth. The nosebowl was jigged in place and 5/16-inch holes were drilled through the previously formed fiberglass flange at fuselage station 17.68 and into the plywood mounting ring. The nosebowl was bolted in place without bonding.

Fins

Though the geometric data for the fins of the HL-20 showed some variation in the thickness of the fins, the decision was made to form them as a constant thickness (7.5 inches) with a radiused leading edge and a blunt trailing edge. This permitted rapid fabrication from a sheet of polystyrene foam, which was used as a core material. Replacing the foam locally along the root and trailing edge was 3/4-inch birch plywood, which, after layup, provided a finished surface without the labor of secondary layups. An integral, oversized mating "tongue" was formed along with the rest of the fin and trimmed to fit in the slot in the body on assembly.

The upper and lower skins of the fins were laid up in two separate cures. The fins were restrained to lie flat as each layup was performed to prevent warpage. Six plies of eight-ounce unidirectional E-glass cloth were placed parallel to the trailing edge before the rest of the skins to form the caps of a spar. These plies tapered in

thickness from ten inches to six inches and tapered in length from full span to mid span. All spar plies spanned the entire length of the tongue. The skin of the fins was two plies of 18-ounce E-glass cloth oriented at 45 degrees with respect to the leading edge. The upper and lower plies overlapped at the leading edge. Peel ply was used over all skin layups and removed later.

Vertical Tail

The vertical tail was similar to the fins in structure. The constant thickness core of 5.5-inch polystyrene foam shown in Figure 19 had a plywood root and trailing edge. The root plywood was match drilled to another plywood sheet. This plywood was bonded to the vehicle to serve as a mounting plate. Fixed 5/16-inch nutplates were attached to the inside surface of the root plywood before assembly to the foam. The skin of the vertical tail was three plies of eight-ounce unidirectional E-glass. The first and last plies were aligned parallel to the leading edge, and the middle ply was at a right angle to the leading edge. Peel ply was used over all skin layups and removed later.

Landing Gear

The landing gear used on the HL-20 Engineering Model were a modified version of a Piper Navajo gear. The nosegear is seen in Figure 20. The struts were replaced by hollow aluminum shafts and bolted solidly rather than being allowed to stroke. All three gear were extended in length. Brakes were removed, and the steering mechanism was removed from the nose gear trunion and replaced by a thrust bearing at the top of the fork. The gear attachment is described in the structures section of this report.

Internal Structure

As work progressed on the fabrication of the upper body panels, the internal structure shown in Figure 21 was being installed in the heatshield skin. Three-quarter-inch plywood bulkheads were bonded in at the 69.47 and 48.98 fuselage stations. These bulkheads extended in height only to the flange; the remainder of the bulkheads would be attached to the upper cockpit skin and joined to the lower sections with plywood panels and 5/16-inch bolts. The 48.98 bulkhead is designed to carry all of the nose gear loads into the shell of the vehicle.

Butting up against the FS 69.47 bulkhead were four longerons that ran the length of the floor and attached to the aft wall (Figure 22). These longerons were designed to carry the loads imposed by the seats and crew. The two inboard longerons are located at buttline 5.37, and the outboard longerons are located at buttline 35.12. Their construction is described in the structures section of this report.

The two large bulkheads at fuselage stations 216.49 and 264.16 shown in Figure 23 were produced directly from the geometric data and laser cut in 3/4-inch plywood with skin offsets and cabin area cutouts. Both of the bulkheads were slotted to fit the four longerons. The aft bulkhead was bonded to the skin with a slurry of epoxy and flocked cotton, then tied to the skins with a three-ply layup of 18-ounce cloth on a 45 degree orientation. The 216.49 bulkhead fits just aft of the preformed flange and was bonded to the flange and the skin, again with epoxy/cotton slurry. Holes were drilled through the plywood and flange and into the aft flange of the center body panel. A series of 5/16-inch bolts connects the aft and center body panels. Unlike the center body panel and cockpit shell, the aft panel is bonded in place and is not removable without great effort.

In order to locally stiffen the heatshield skin, spanwise stiffeners were bonded to the inside of the skin every 16 inches for almost the entire vehicle length. These members were trapezoidal in cross section and made of 10 pound per cubic foot

polyurethane foam. Two plies of nine-ounce bidirectional E-glass cloth on a 45-degree orientation were laminated over the top of the stiffeners, lapping several inches onto the surrounding skin.

Three plywood pads were installed in the floor of the vehicle as hard points for mounting the vehicle to its support structure. The aft pads measured 16 inches square and were bonded to the floor with an epoxy/cotton slurry in a position directly under the FS 264.16 bulkhead (prior to bulkhead attachment) and butting up against the outboard side of the outboard longeron. The entire pad was covered with 12 plies of 18-ounce cloth, alternating 45 and 0 degree orientations. The plies lapped onto the skin a maximum of 12 inches from the perimeter of the plywood pads and also lapped up to the top of the longeron. After installation of the FS 264.16 bulkhead, three more plies on a 45 degree orientation tied the bulkhead to the pad. The forward cradle attach pad, also 3/4-inch birch plywood, measured 10 inches wide and 12 inches long and was bonded in between the two inboard longerons. A tapered bed of epoxy/cotton filler beneath the pad allowed the pad to lie level despite the local slope in the floor. Six plies of 18-ounce cloth on a 45 degree orientation tied the pad into the bulkhead, longerons, and skin. Steel plates measuring 3/4 inches thick by 12 inches square were attached to the bottom of the vehicle under each of the three plywood pads. Attaching each of the plates were four 5/8 inch bolts passing through 1-inch diameter bushings. On the aft pads, the bushings protruded into steel angles on the inside surface of the pads. The angles were 1/4 inch thick and had 6-inch-wide flanges, and were also bolted through the bulkhead with two unbushed 5/8 inch bolts. The forward hard point had a 1/4 steel plate instead of the angles. Due to the local slope of the surface at the forward attach plate, a tapered bed of epoxy/cotton fills the gap between the skin and the exterior steel plate.

STRUCTURE

General Structure

The HL-20 full scale engineering model is constructed largely of 18-ounce woven E-glass roving. The epoxy resin used was Apco 2410 with Apco 2183 room temperature cure hardener. In general, the vehicle shell consisted of five plies oriented at 45 degrees to the centerline and measuring an average of .150 inches thick. Three additional plies were placed in the mating flange areas, bringing the total thickness in those areas up to an average .240 inches. In the sharp corners along the flanges, approximately .05 square inches of carbon roving were added for increased durability. Splices were overlapped a minimum of 2 inches. The layup was performed with brushes, squeegees, and rollers. Both the interior and exterior surfaces of the shell were laid up with a ply of light weight Dacron cloth, which was removed after cure to leave a textured surface. The parts were not vacuum bagged or oven cured. Splices between adjacent parts along the centerline of the vehicle were performed with both interior and exterior tapes that at least duplicated the existing layups. A preformed joggle on the exterior surface allowed these layups to remain flush with the vehicle contours.

All bulkheads are of 3/4-inch nine-ply birch plywood. The bulkheads are bonded in place with a mixture of the previously mentioned epoxy and flocked cotton fibers. Also, three plies of 18-ounce fiberglass with a 45-degree orientation tie the bulkheads to the skin of the model.

Longeron Structure

Four longerons run along the floor of the HL-10 model from the FS 109 bulkhead to the aft surface. These members are designed and built to carry those loads imposed by the seats and crew when the vehicle is in both the horizontal and vertical positions.

The longerons as shown in Figure 24 have as a core material nine-ply birch plywood to provide bearing strength for seat attachment. Each of the longerons has a carbon fiber/epoxy spar cap with continuous carbon fibers along the entire length of the longeron. Heavy bidirectional glass layups form the sides of the longerons. These plies lap onto the floor of the vehicle, forming the lower spar cap.

To calculate the moment of inertia of the longerons, the areas of the various elements of the cross section were modulus weighted using the modulus of elasticity of bidirectional fiberglass (2.4×10^6 psi) as a reference. The properties of the materials used in the longerons are as follows (the ultimate strengths shown are for compression and represent the worst case):

FIBERGLASS/EPOXY

(45-DEGREE ORIENTATION) $E = 2.4 \times 10^6$ psi $F_{ult} = 13,800$ psi

CARBON ROVING/EPOXY

(0-DEGREE ORIENTATION) $E = 11.4 \times 10^6$ psi $F_{ult} = 80,000$ psi

NINE-PLY BIRCH PLYWOOD $E = .80 \times 10^6$ psi $F_{ult} = 5000$ psi

The vertical center of gravity for the beam model was calculated to be 3.01 inches from the lower surface of the vehicle skin. The moment of inertia of the section was determined to be 20.13 inches⁴.

Load Case 1 from the paper entitled "Personnel Launch System Mockup Design and Fabrication Proposal" (included as Appendix B in this report) represents the fully loaded vehicle on its landing gear. The moment and shear diagrams presented in the design proposal are valid for the completed vehicle. Rather than the shell of the vehicle carrying the total load, the present analysis demonstrates the four longerons' ability to carry the loads imposed by the crew and seats. The longerons are assumed to be simply supported at the FS 109 and FS 216 bulkheads. Each crew member has

a weight of 297 lb and is at rest in a seat weighing 75 lb. For purposes of analysis, the eight crew members and seats are assumed to be an equally distributed load between the two bulkheads (two additional crew members are located aft of the FS 216 bulkhead and are not considered for this load case. The maximum bending stresses associated with this load case are approximately 1500 psi. In this situation, the upper carbon spar cap is in compression and the lower fiberglass cap is in tension. The ultimate strength for 45-degree E-glass/epoxy is 15.1 ksi, so the safety factor for the lower cap is 10. The upper cap has a safety factor of 40 in this situation. Deflections, as given by the formula

$$y = \frac{Wx(l-x)[l^2+x(l-x)]}{24EI},$$

where l is the overall length of the beam (107 inches) and W is the total distributed load (744 lb). The deflection curve shows a maximum deflection for the longerons to be slightly less than 1/4 inch for this load case.

Load Case 1a is identical to Load Case 1 except that the vehicle rests on the cradle rather than on the gear. Here the four longerons are supported at the FS 264 bulkhead, and the weight of all ten crew members must be considered. Again, the ends are assumed to be simply supported, and the load is assumed to be evenly distributed along the length of each longeron. A maximum bending stress of 2700 psi was calculated for this case, resulting in a safety factor of 5.6 for the fiberglass lower cap and 29.6 for the carbon upper cap. The maximum deflection was found to be .93 inches. This simple analysis does not consider the contribution of the FS 216 bulkhead, which in reality will carry much of the load into the shell structure, relieving the longeron stress and decreasing the deflections.

Main Gear Bulkhead Structure

Load Case 1a, in which the fully loaded vehicle rests on the cradle, is the worst case for bending across the bulkhead structure. The longerons are conservatively modeled as if they were simply supported at the FS 109 and FS 264 bulkheads. Thus the load supported at the FS 264 bulkhead is half of the total crew and seat weight, or 1860 lb. This load was assumed to be a distributed load between the two outboard longerons ($y = \pm 29$). The cradle attachment points are at butt line 51. Here the maximum bending moment is at the center of the beam and is given by the formula

$$M_{\max} = 1/8 WL (1 + 2a)$$

where W is the total load, L is the total length, and a is the fraction of beam that is unloaded at ends. The maximum moment was determined to be 34,000 in-lb. The lower cap stress is 3545 psi, giving a safety factor of 4.3. The upper cap stress, then, is 7430 psi. The upper cap is made of unidirectional fiberglass with a ultimate compressive strength of 49,000 psi. The safety factor in the upper cap is 6.6. In practice, a portion of the load placed on the FS 264 bulkhead will be transmitted to the FS 416 bulkhead via the vehicle shell, relieving the stresses on the aft bulkhead.

VEHICLE HANDLING AND MAINTENANCE

General Maintenance

The epoxy system used in the construction of the HL-20 Engineering model experiences a significant degradation of structural properties at a temperature of approximately 170 degrees F. Care should be taken when exposing the dark painted surfaces to direct sunlight for prolonged periods. This may be a consideration if the vehicle is placed in the upright position, exposing the dark gray bottom of the vehicle.

The white paint used on the upper surfaces of the vehicle is a one stage urethane system. The textured heatshield paint is acrylic based. The entire surface of the vehicle may be cleaned with a mild soap solution. Waxing is not recommended.

Special care should be taken of the nose of the vehicle (forward of the nose gear box), since the skin here is thinner and more susceptible to denting and puncturing.

Covering the vehicle during transport should be avoided if possible, since it has been found that repeated rubbing of a plastic cover can cause abrasions in the paint.

Fins and Vertical Tail

A minimum of three people are required to install a fin. A stable platform approximately 40 inches in height is needed. The fin is positioned with the tongue just outside of the hole, and the angle of the fin is adjusted so that it is parallel to the walls of the hole. It is helpful to have a fourth person inside the vehicle to support the fin as it is lowered into position. Care should be taken to keep fingers out of the fin root area during installation. After the fin is in place, a 5/16-inch bolt is installed from inside the vehicle to secure the leading edge of the fin. This bolt is located in the fin root just outboard of the main gear box. The fin may require some alignment before the bolt will engage. As with all bolts engaging into nutplates, the proper length bolt must be used to avoid damage to the nutplate. Do not over torque the bolt - if the bolt becomes

difficult to turn, it is probably the wrong length. The five bolts on the aft end of the vehicle which pass through the aft wall and into the wing tongue are not needed unless the vehicle is to be subjected to high winds or if unusual loads are in some way applied to the fins. With the bolts in place, the fins have been shown to be capable of supporting a 180-lb weight placed at the tip.

Removal of the fins requires four people, one of whom pushes the fin out from inside the vehicle. The fins should be stored with the white side up when exposed to sunlight to avoid the possibility of overheating. The fins should not be allowed to rest on the corners of the tongue, as this position may damage the flanges. Placing the leading edge down and leaning the fin against a soft surface is the best position for temporary storage.

The vertical tail is installed by placing the tail in place on top of the vehicle and fastening it with 5/16-inch bolts. Though holes and nutplates are provided for ten bolts, no more than four are needed unless the vehicle is to be subjected to high winds or other unusual loads. The four bolts should be placed near the extreme ends of the tail with two on the left side and two on the right side.

Landing Gear

It is suggested that the trunions remain bolted to the vehicle and only the gear legs be removed for transport, since access to these bolts is much better. The drag links may be disconnected at either end, if desired, to allow the trunion to be pivoted. The gear legs can then be installed or removed without raising the vehicle an excessive amount.

The tires are standard general aviation grade and should be kept inflated to the manufacturer's suggested pressure.

A thrust bearing just above the nose gear fork allows smooth steering of the nose gear. It should be kept as clean as possible.

Transport

The HL-20 Engineering Model is transported on a steel structure that attaches to three hard points on the bottom of the vehicle. Mating the vehicle to the supporting structure should be done on as level a surface as possible. The HL-20 may be backed over the supporting structure by simply rolling it on its gear. All three wheels should roll on ramps at least four inches thick to provide clearance. Once the vehicle is positioned correctly, the support structure can be jacked up until the three one-inch pins can be installed through each of the clevises.

The spreader beams are slid through the spaces in the lower support structure and bolted in place. The four straps of the harness with which the vehicle is lifted should be at least twenty feet long to insure that they will not bear against the surface of the vehicle. The weight of the vehicle as delivered with the fins and vertical tail attached was measured to be 2484 pounds.

Conclusion

An engineering research model of the NASA HL-20 Personnel Launch System vehicle concept was designed and fabricated by the Mars Mission Research Center at North Carolina State University. The structural schedule requirements dictated the introduction of innovative methods which were pioneered in house during the course of the project. The completed vehicle represents sound structural design practice with adequate safety margins to enable the research objectives to be obtained.

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APPENDIX A - PLS PROGRAM PARTICIPANTS

MARS MISSION RESEARCH CENTER

Dr. Fred R. DeJarnette, Director

PLS PROJECT DIRECTOR

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Glenn S. Tetterton

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Thurman Exum, Coordinator

Dennis Hugley, Design Specialist
Don Wilson, Machinist
Robert Williams, Welder

Students:

Stephanie Connor
Gary Eure
Carl F. Jones
John Jones
Timothy Little

TABLE 1 - MOLD CROSS SECTION SPECIFICATIONS

| FUSELAGE STATION (ft) | FUSELAGE STATION (in) | THICKNESS (in) |
|-----------------------|-----------------------|----------------|
| 1.473 | 17.68 | 2.57 |
| 1.695 | 20.34 | 2.66 |
| 2.029 | 24.34 | 4.01 |
| 2.477 | 29.73 | 5.38 |
| 3.044 | 36.53 | 6.80 |
| 3.503 | 42.03 | 5.50 |
| 4.081 | 48.98 | 6.94 |
| 4.525 | 54.30 | 5.33 |
| 4.737 | 56.84 | 2.54 |
| 4.950 | 59.40 | 2.56 |
| 5.172 | 62.07 | 2.67 |
| 5.541 | 66.50 | 4.43 |
| 5.789 | 69.47 | 2.97 |
| 6.026 | 72.31 | 2.84 |
| 6.264 | 75.17 | 2.86 |
| 6.497 | 77.96 | 2.79 |
| 6.719 | 80.63 | 2.67 |
| 7.037 | 84.44 | 3.81 |
| 7.278 | 87.34 | 2.89 |
| 7.518 | 90.22 | 2.88 |
| 7.752 | 93.03 | 2.81 |
| 7.981 | 95.78 | 2.75 |
| 8.206 | 98.47 | 2.69 |
| 8.537 | 102.44 | 3.97 |
| 9.085 | 109.02 | 6.58 |
| 9.530 | 114.36 | 5.34 |
| 10.096 | 121.15 | 6.79 |
| 10.998 | 131.97 | 10.82 |
| 12.021 | 144.26 | 12.29 |
| 13.045 | 156.54 | 12.28 |
| 14.064 | 168.77 | 12.23 |
| 14.974 | 179.68 | 10.92 |
| 15.997 | 191.96 | 12.28 |
| 17.018 | 204.21 | 12.25 |
| 18.041 | 216.49 | 12.28 |
| 19.062 | 228.74 | 12.25 |
| 19.970 | 239.64 | 10.90 |
| 20.990 | 251.88 | 12.24 |
| 22.013 | 264.16 | 12.27 |
| 23.034 | 276.41 | 12.26 |
| 24.053 | 288.64 | 12.23 |
| 24.960 | 299.52 | 10.88 |
| 25.979 | 311.75 | 12.23 |
| 27.002 | 324.02 | 12.27 |
| 28.252 | 339.02 | 15.00 |

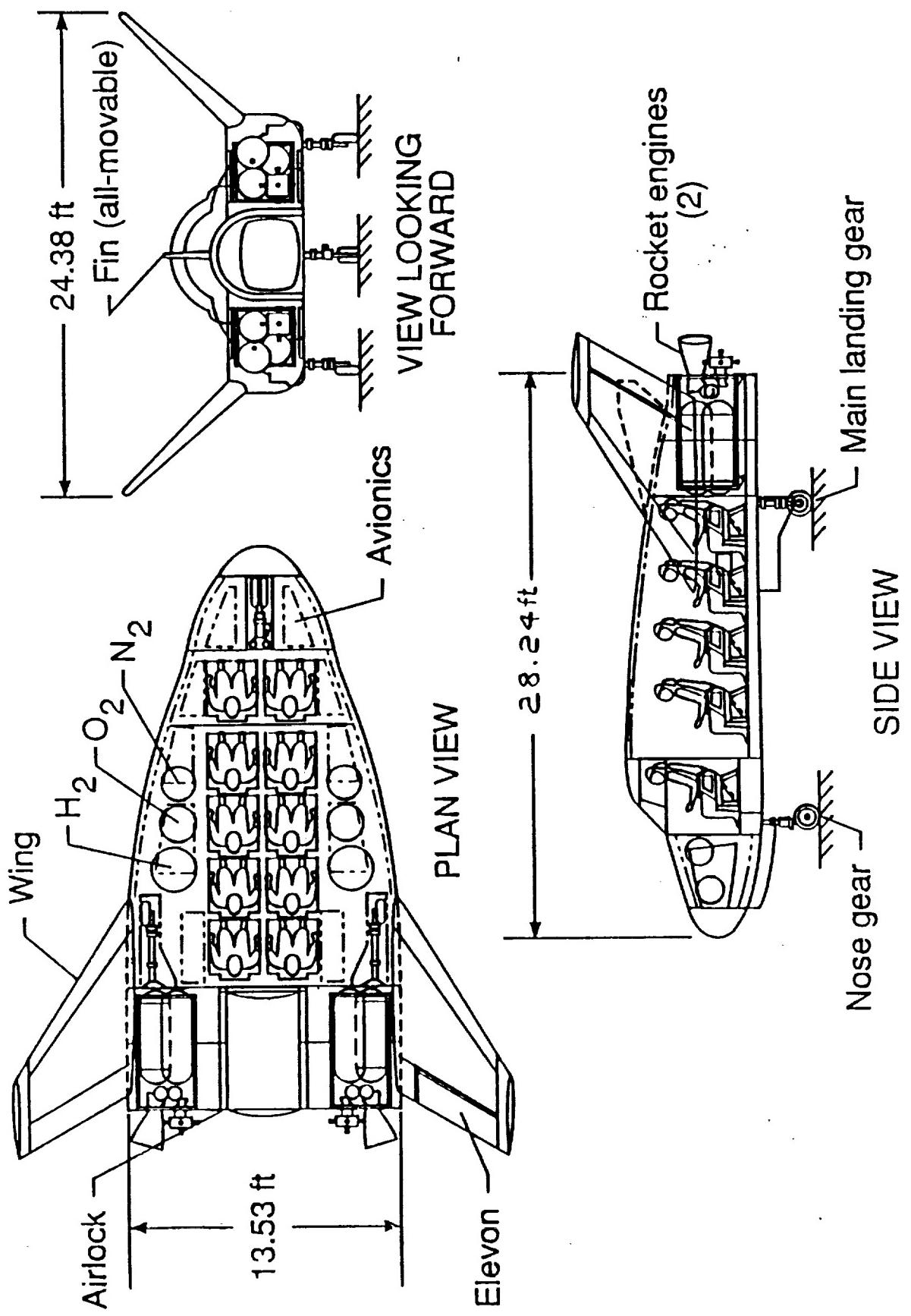


FIGURE 1 - HL-20 PLS CONFIGURATION

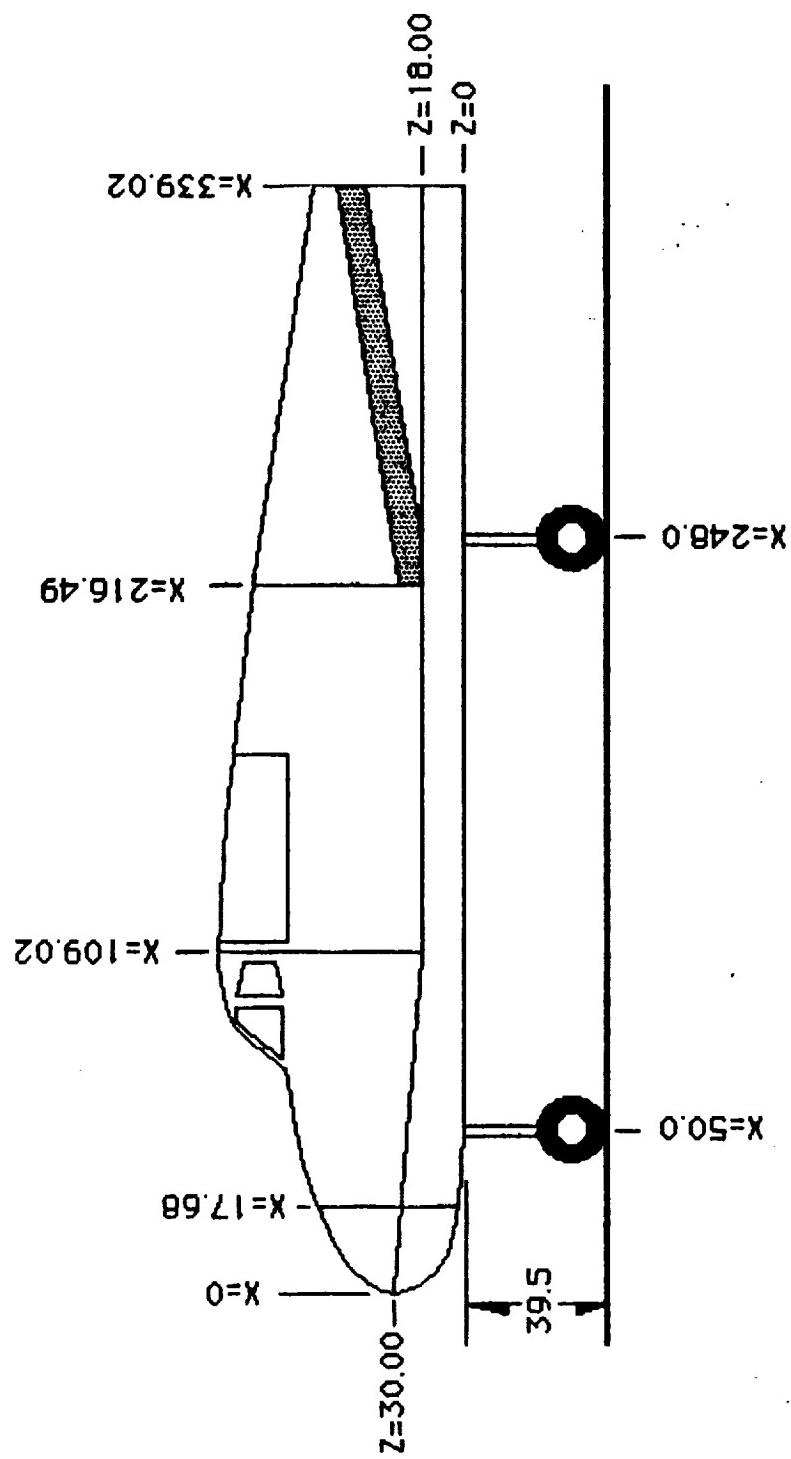


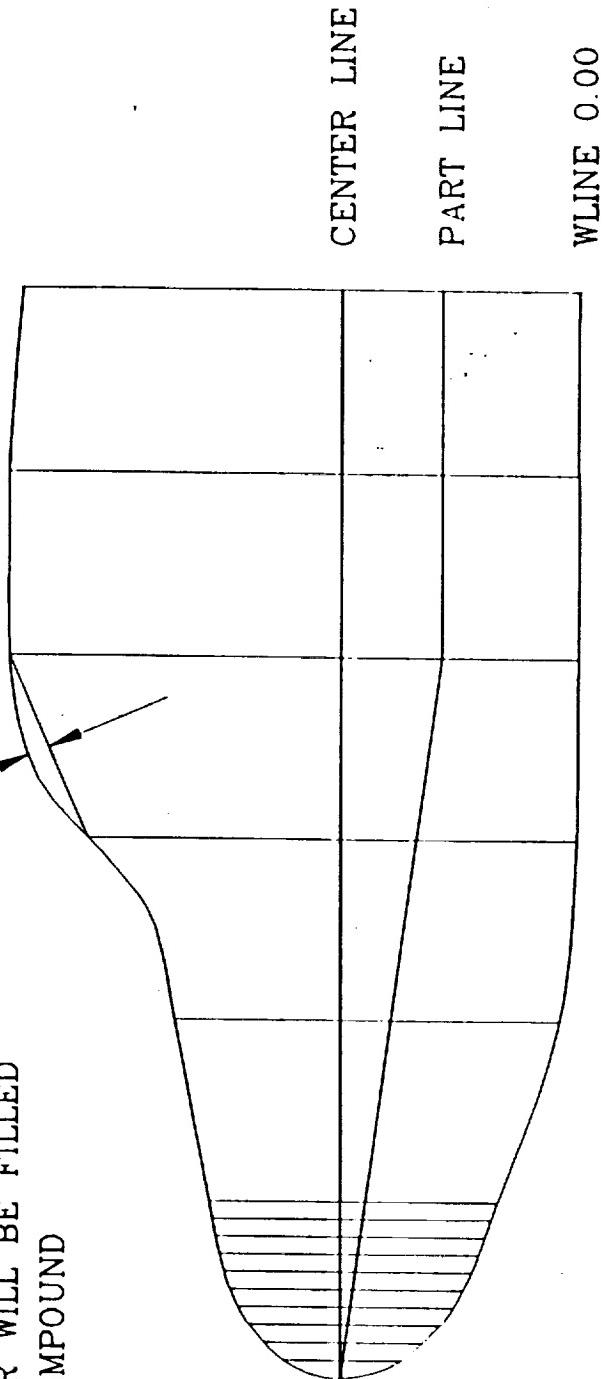
FIGURE 2 - HL-20 GEOMETRY REFERENCES

PLS OUTER MOLD LINE ERROR ANALYSIS

TEMPLATES ARE ON 0.10, 0.25, 0.5, 1.0
FOOT LONGITUDINAL SPACING
AS REQUIRED TO MEET TOLERANCE

UNDERCUT ERROR WILL BE FILLED
WITH FAIRING COMPOUND

OVERCUT ERROR 0.0 BY DESIGN
UNDERCUT ERROR 0.10 INCHES MAX
(EXAMPLE GROSSLY EXAGGERATED)



NASA SUPPLIED 90,000 DATA POINTS
COMPRISING 250 FUSELAGE STATIONS

NCSU SELECTED 58 FUSELAGE STATIONS
TO LIMIT DIMENSIONAL ERROR TO 0.10 INCH
FROM TRUE OUTER MOLD LINE

NCSU / NASA

FIGURE 3a - OUTER MOLD LINE ERROR ANALYSIS

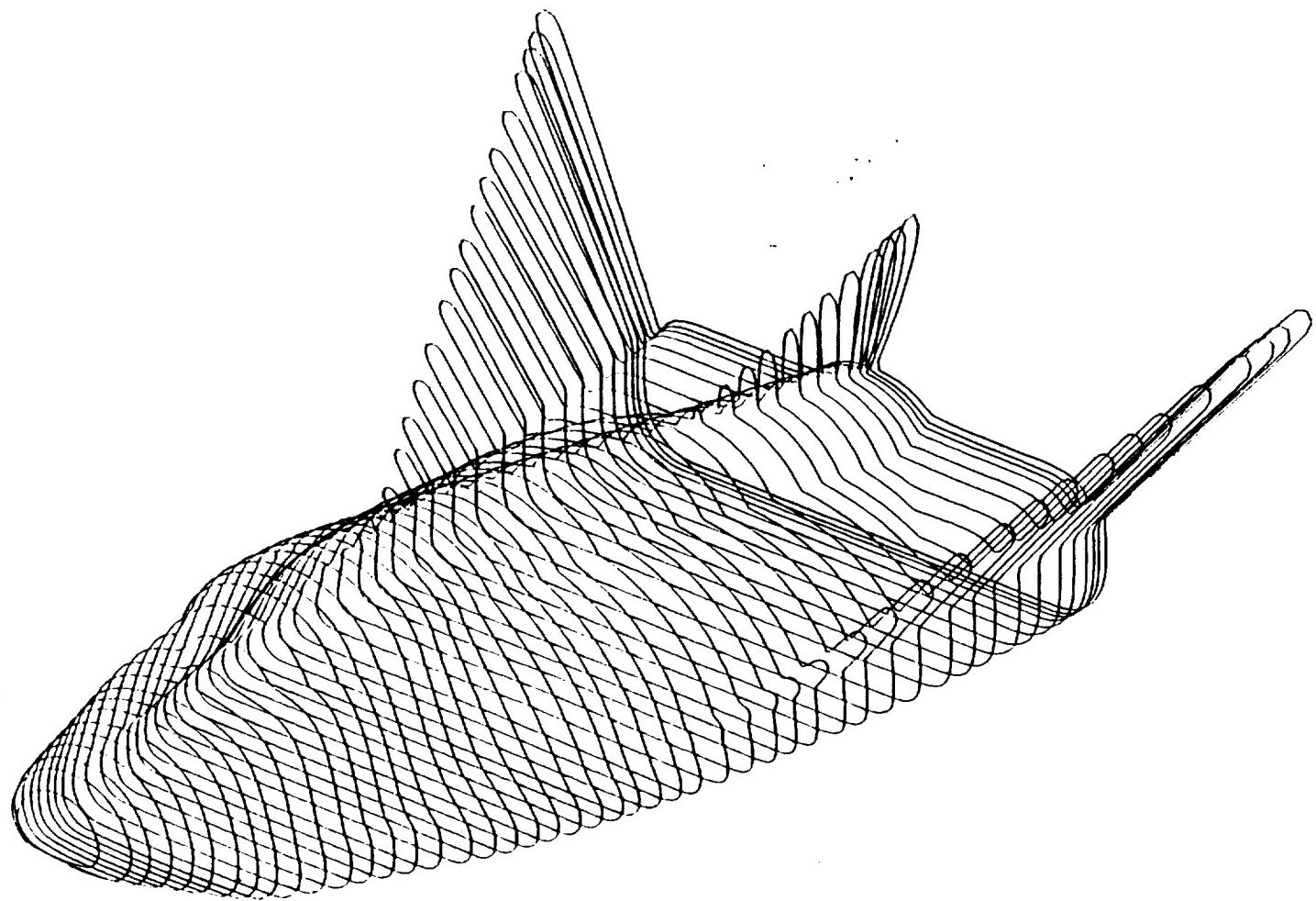
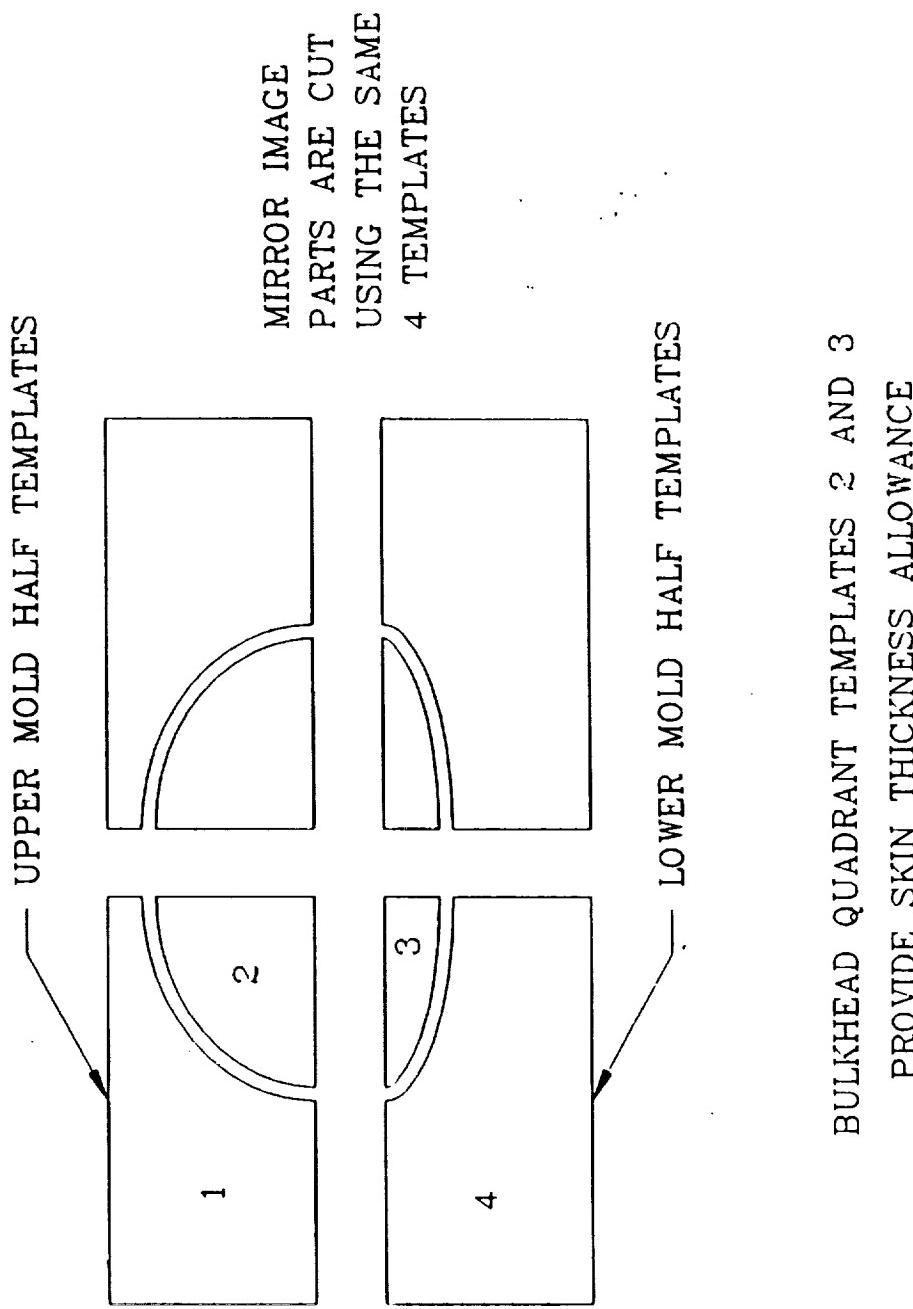


FIGURE 3b - REQUIRED CROSS SECTIONS

TYPICAL FUSELAGE STATION TEMPLATE REQUIREMENTS



NCSU/NASA

FIGURE 4a - CROSS SECTION TEMPLATE MODIFICATIONS

FUSELAGE STATION LASER CUTTING GEOMETRY

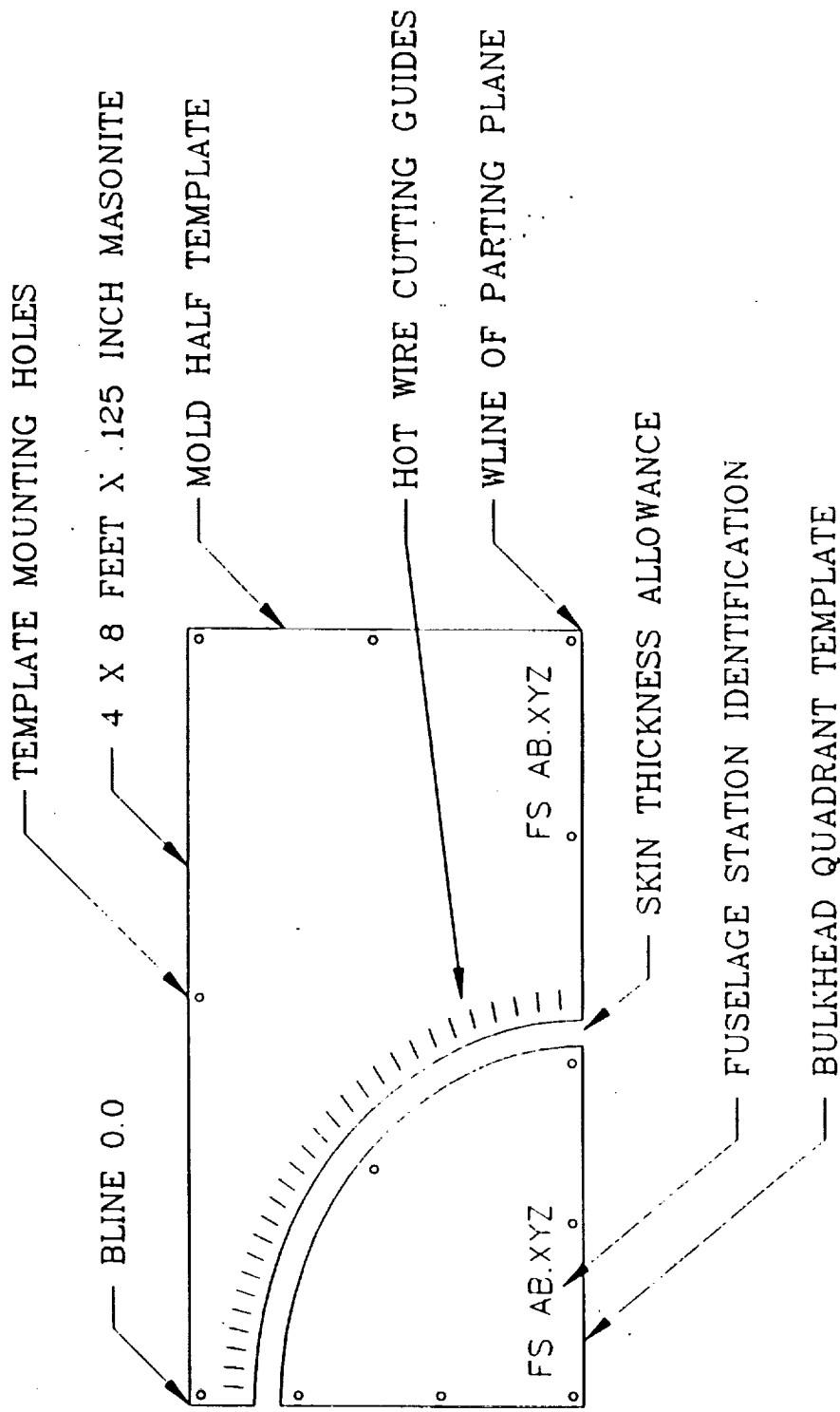


FIGURE 4b - TEMPLATE DETAILS

NCSU/NASA

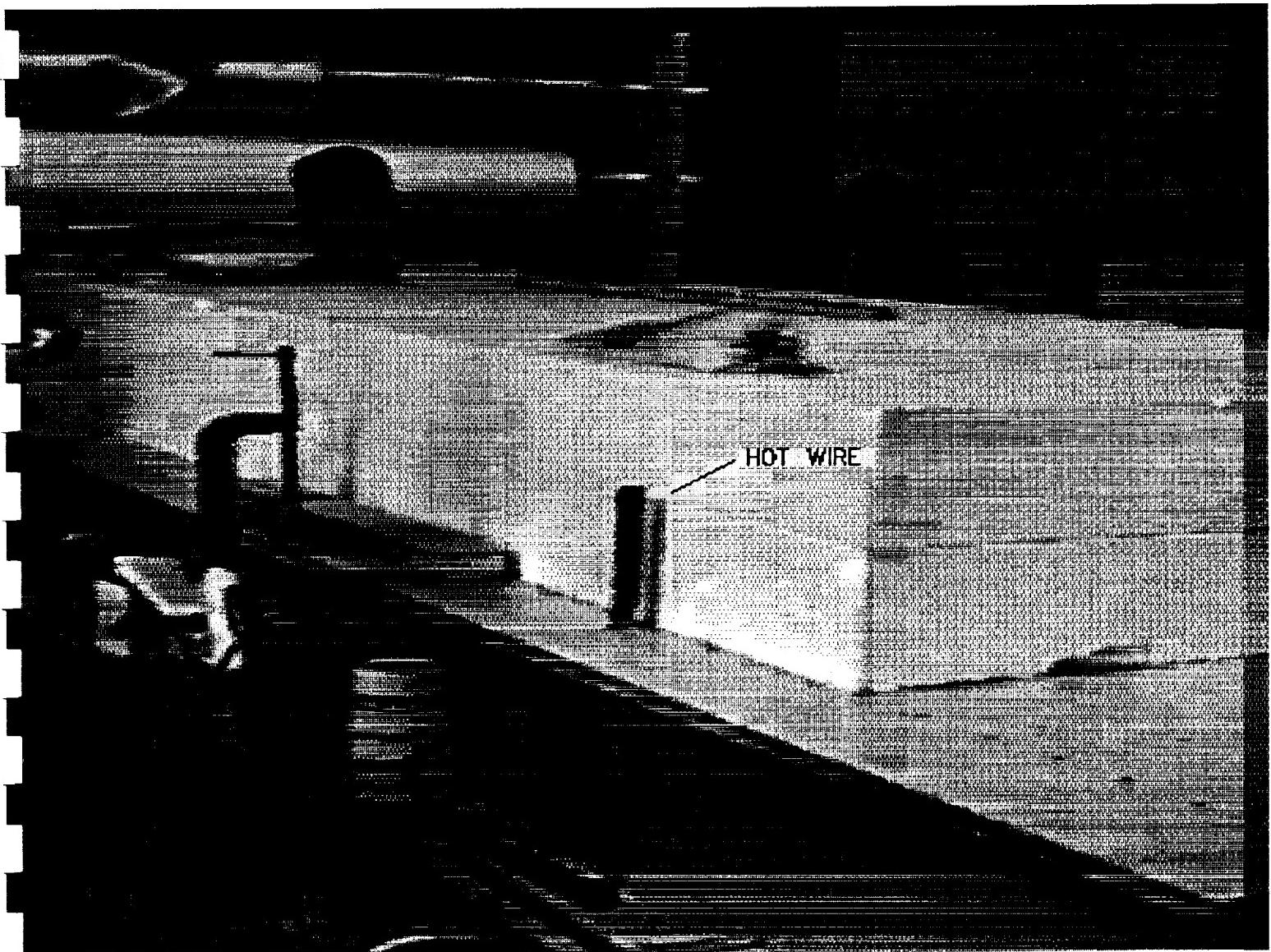


FIGURE 5 - FOAM BLOCK THICKNESS CUT

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FIGURE 6 - HOTWIRING OF INDIVIDUAL MOLD SECTION

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FIGURE 7 - FOAM MOLD ASSEMBLY

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FIGURE 8 - TYPICAL LAYUP OF FIBERGLASS PART

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FIGURE 9 - REMOVAL OF CURED PART FROM MOLD

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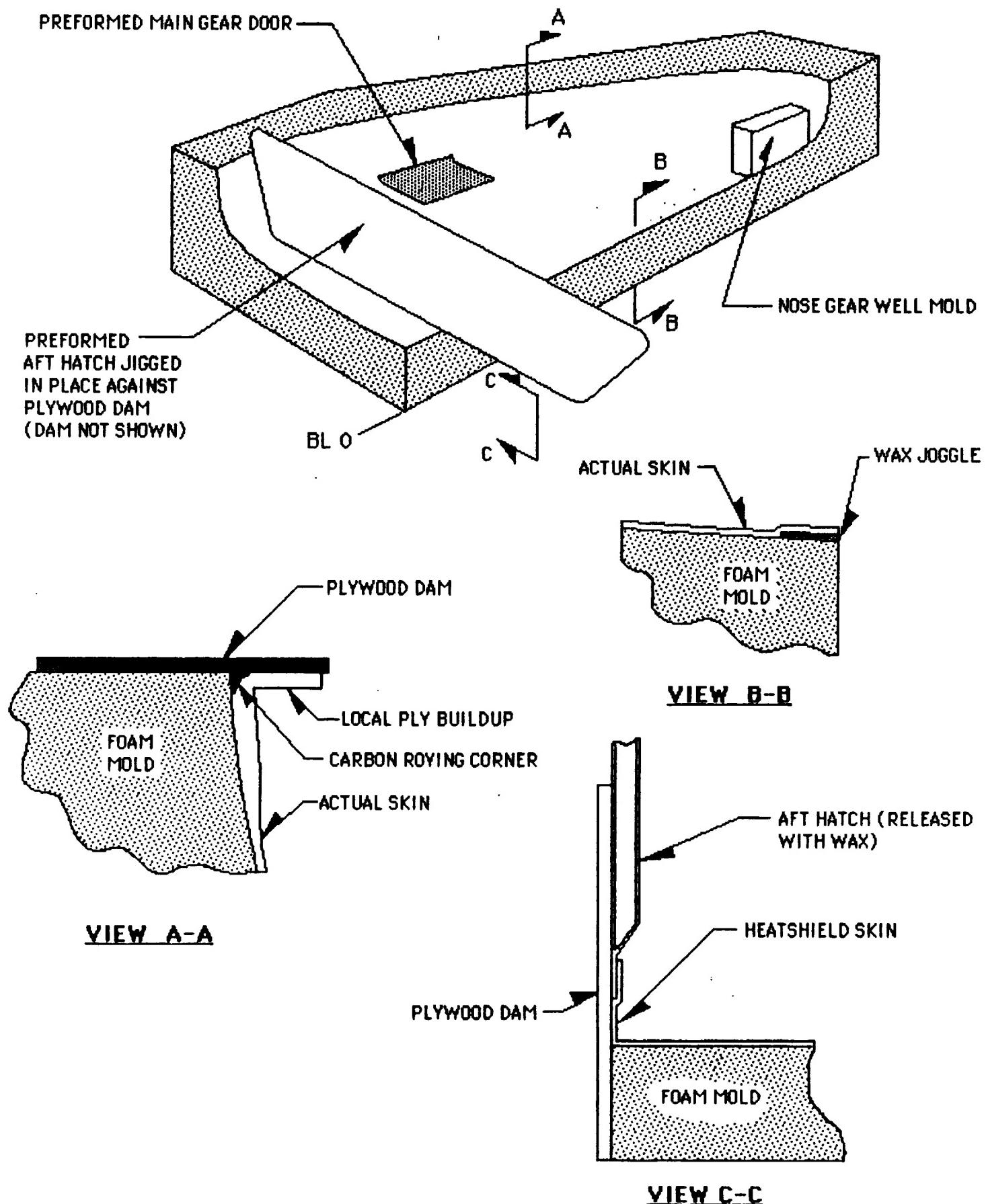


FIGURE 10 - HEATSHIELD MOLD DETAIL

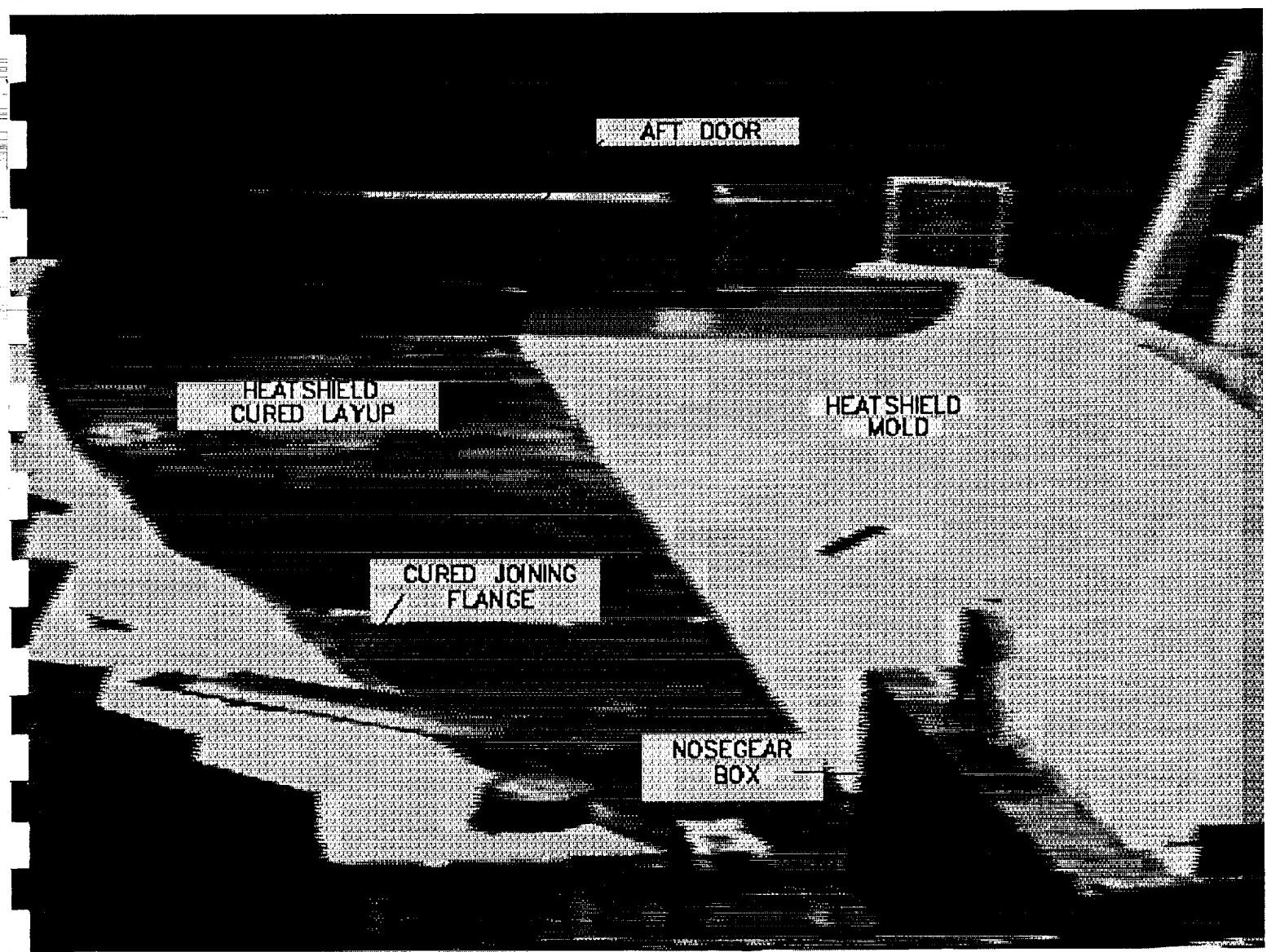


FIGURE 11 - HEATSHILED LAYUP

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FIGURE 12 - COCKPIT MOLD WITH WINDOWS INSTALLED

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The windshields are molded into the cabin to produce a flush fit. The plexiglass panels are released with wax and placed on the foam mold before the forward panel layup. The layup covers the windows completely. Later, after the part is removed from the mold, the windows are taken out to allow trimming of the flanges. The plexiglass is reinstalled with silicone adhesive.

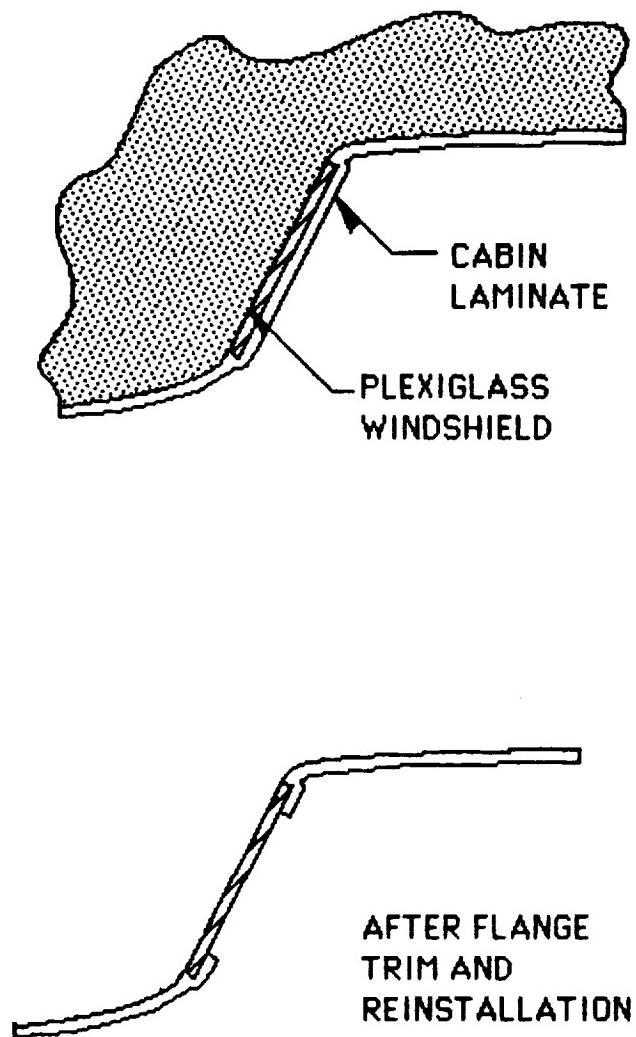


FIGURE 13 - WINDSHIELD DETAIL

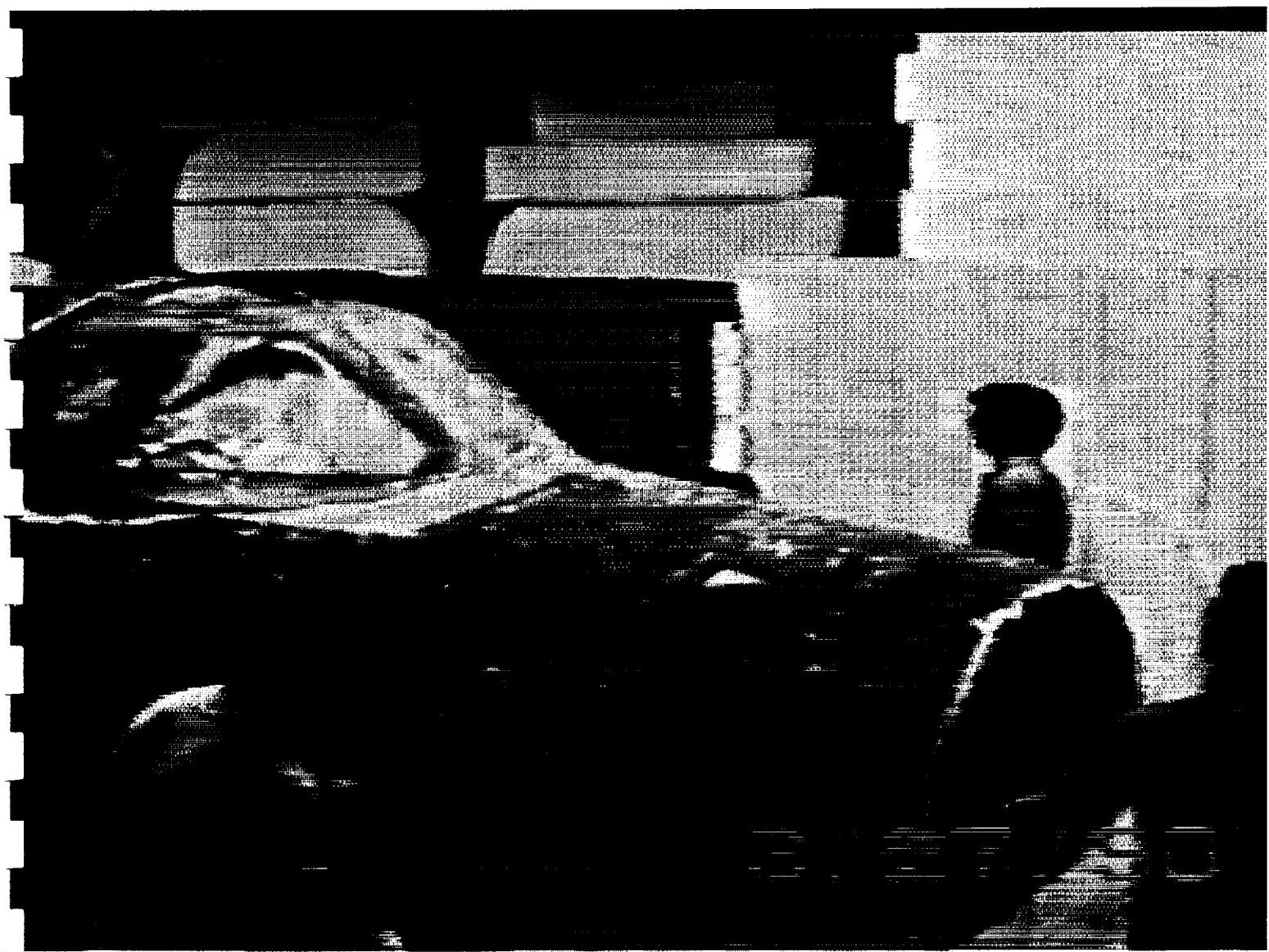


FIGURE 14 - PLACEMENT OF COCKPIT SECTION

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In order to form a flush fitting door on the top of the cabin, a two step layup is required. The area of the mold that forms the door is covered with a plastic release film, and the door is laid up. After cure, the door is removed and trimmed. The door is placed back in the mold and released on its inner surface. The panel skin is formed over the door. After the entire part is removed from the mold the door flanges are trimmed, and nutplates are mounted.

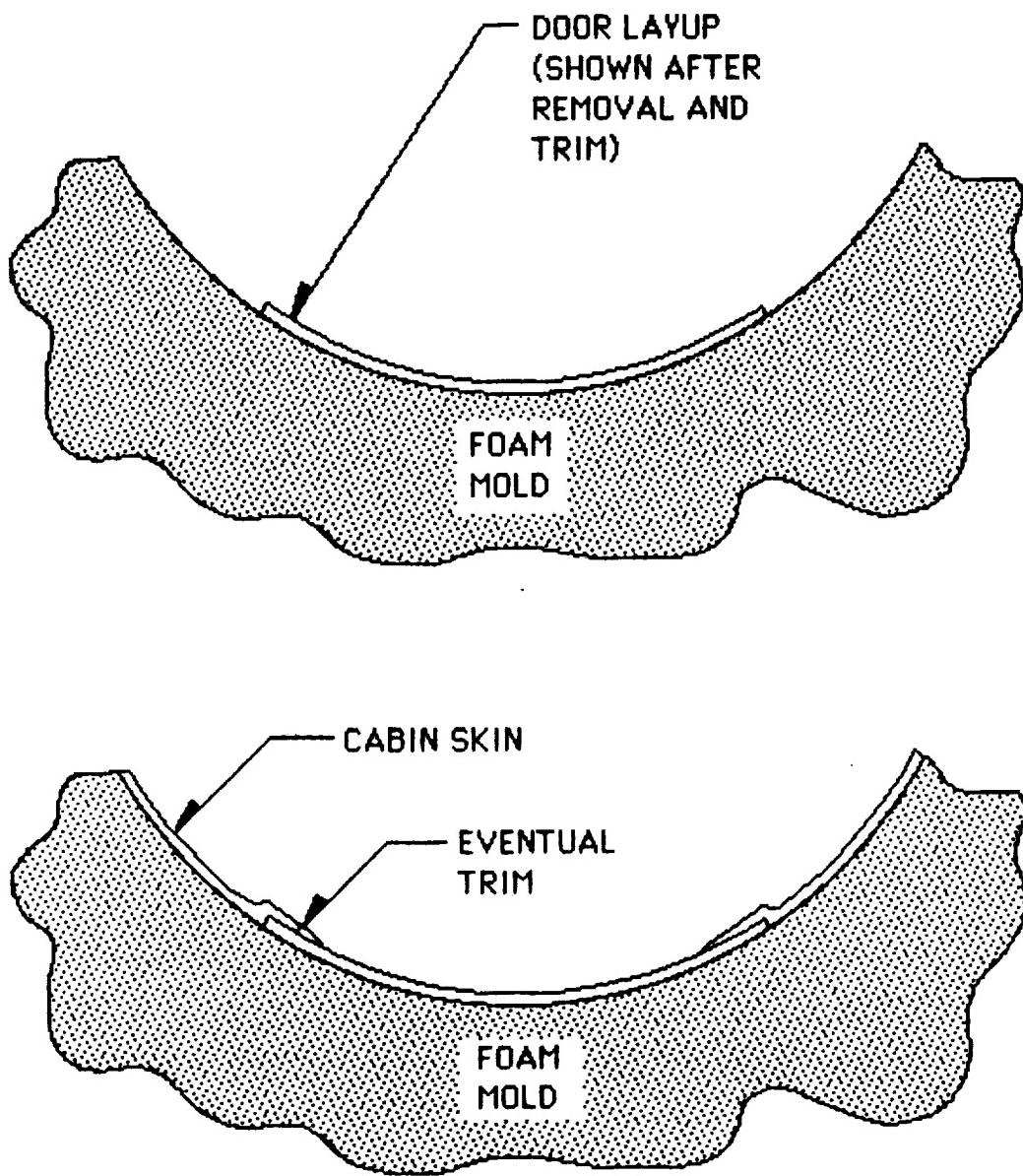


FIGURE 15 - UPPER HATCH FLANGE FABRICATION



FIGURE 16 - PLACEMENT OF MIDDLE FUSELAGE SECTION

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FIGURE 17 - PLACEMENT OF AFT FUSELAGE SECTION

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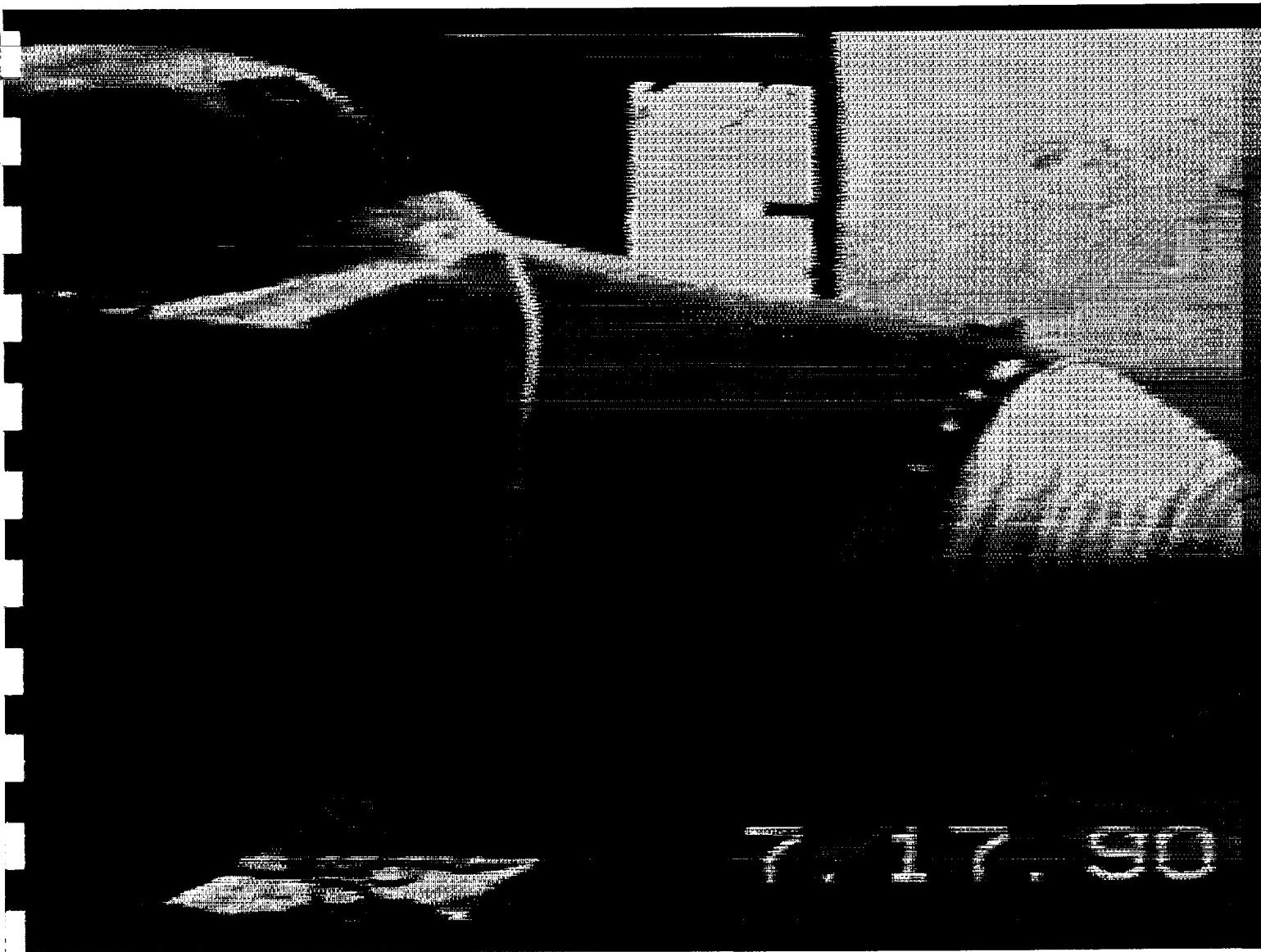


FIGURE 18 - NOSE BOWL FABRICATION

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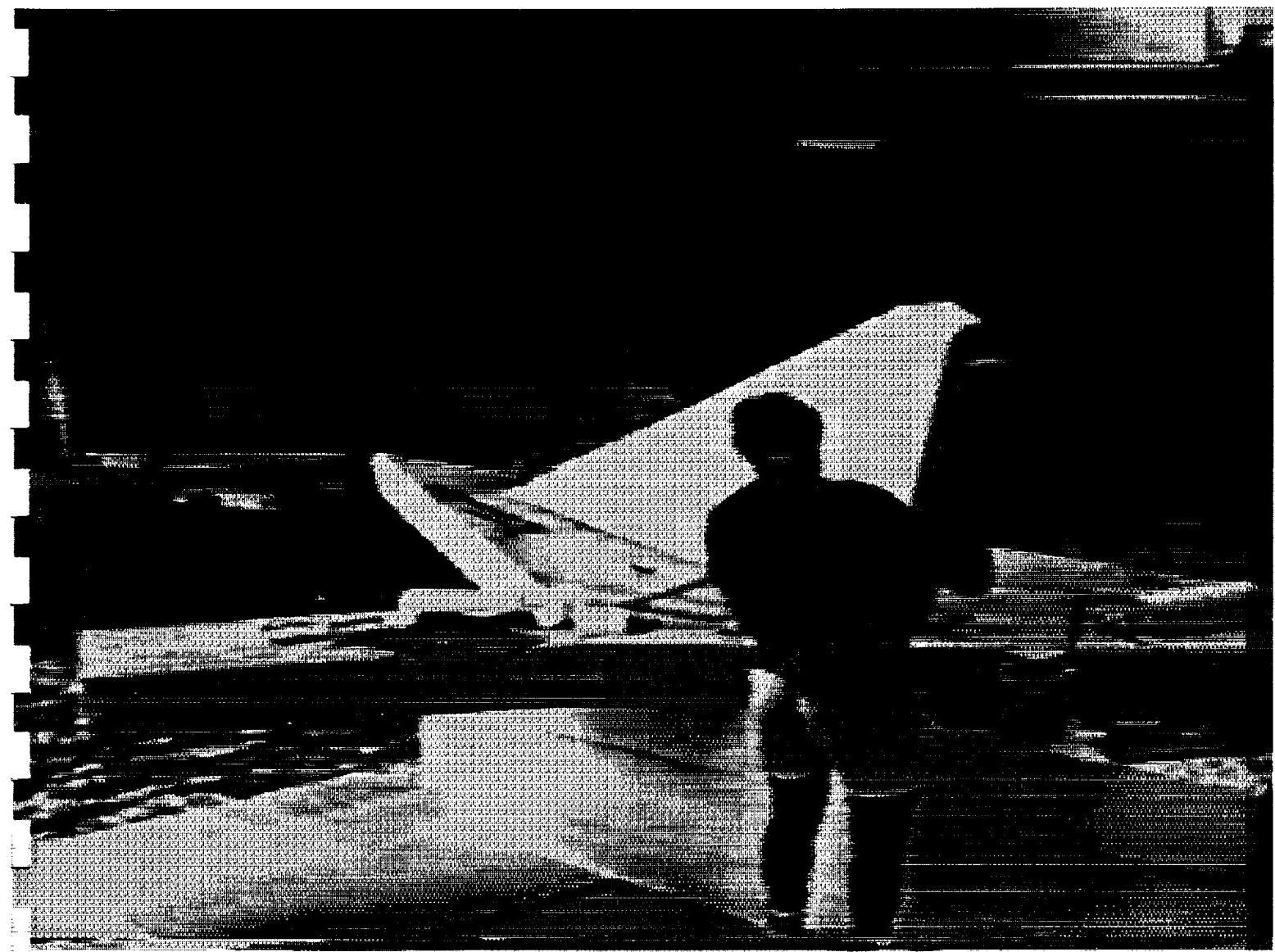


FIGURE 19 - VERTICAL TAIL CORE ASSEMBLY

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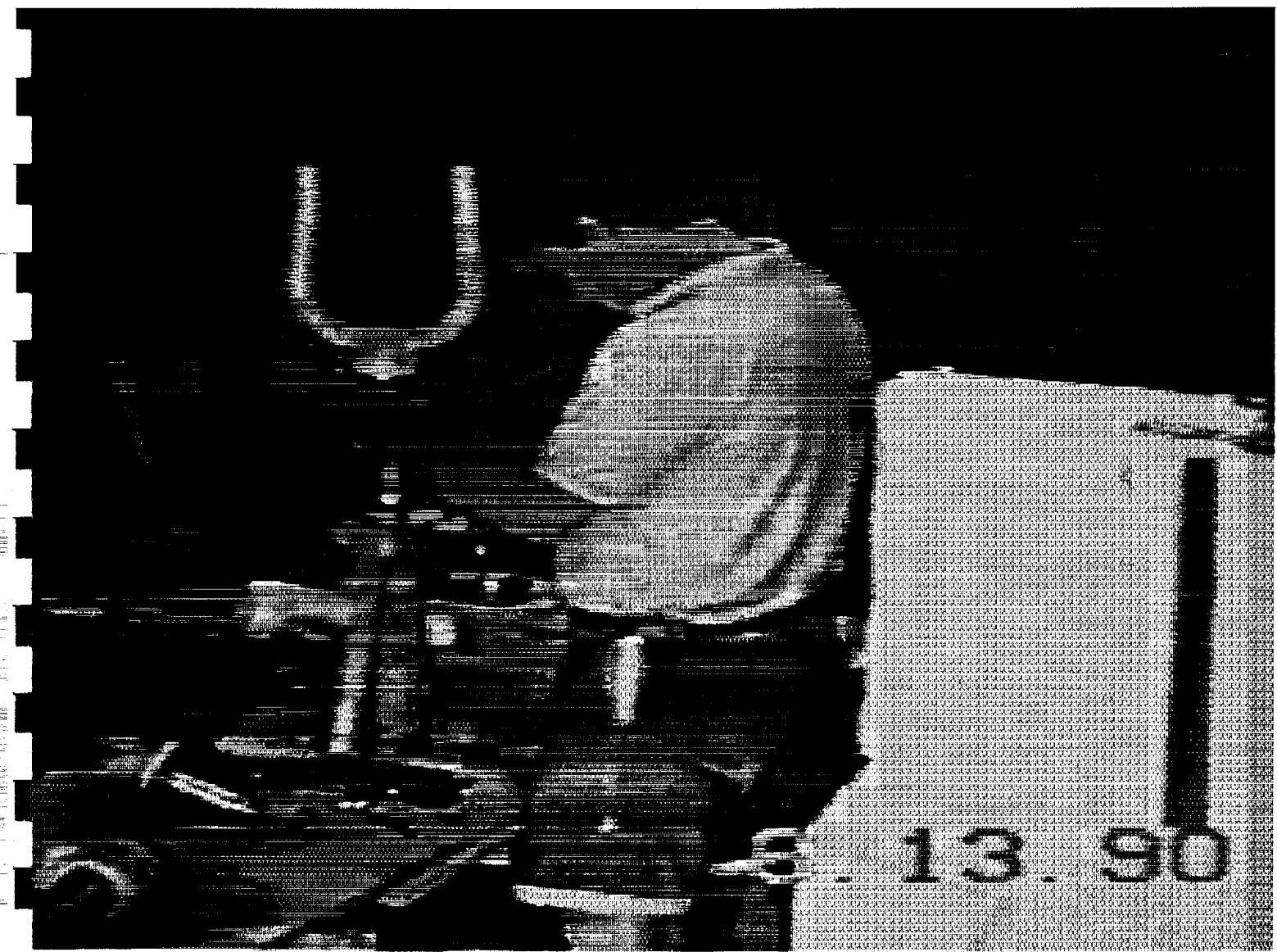
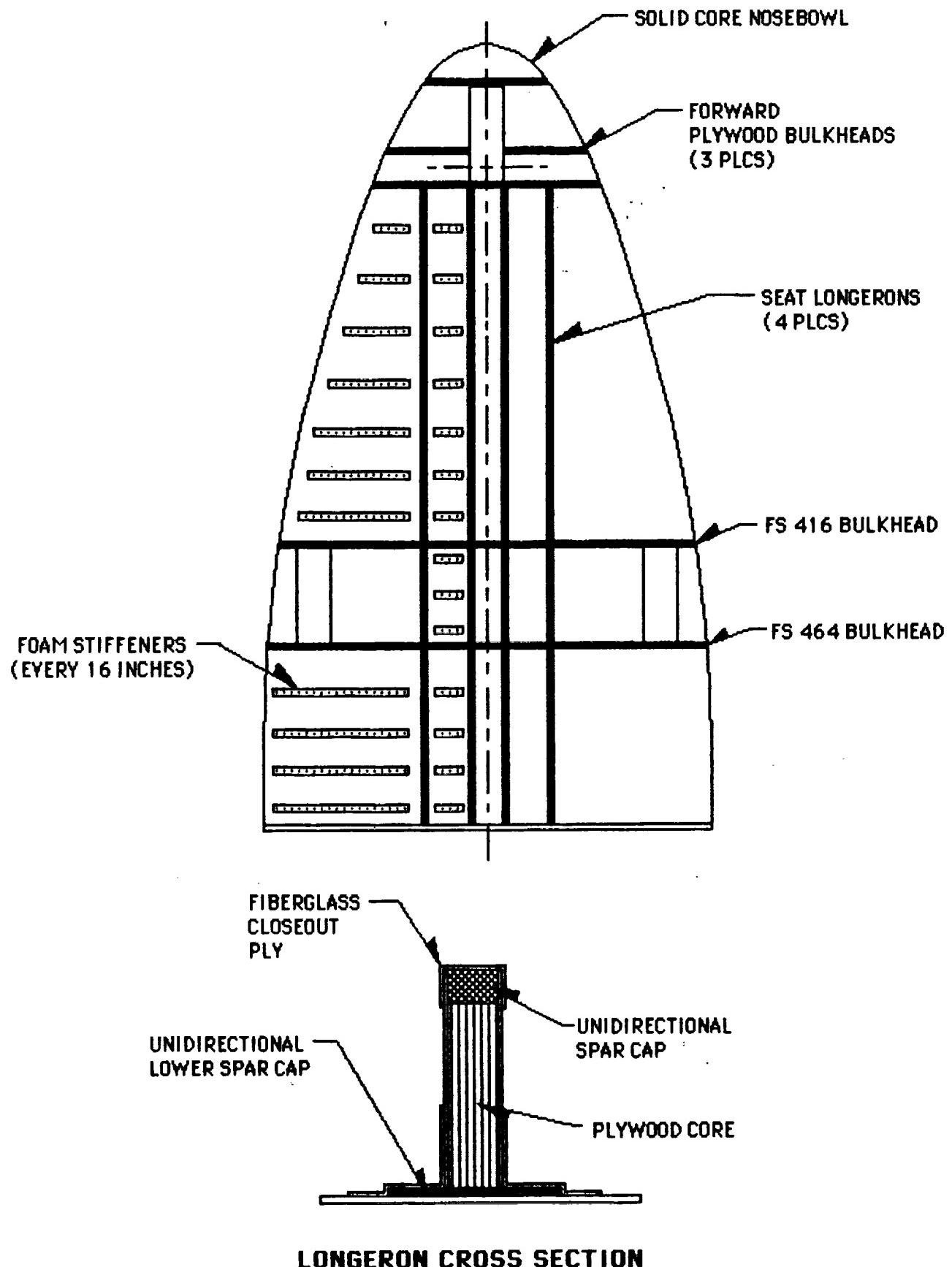


FIGURE 20 - LANDING GEAR MODIFICATION

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INTERNAL STRUCTURE LAYOUT



LONGERON CROSS SECTION

FIGURE 21 - INTERNAL STRUCTURE LAYOUT

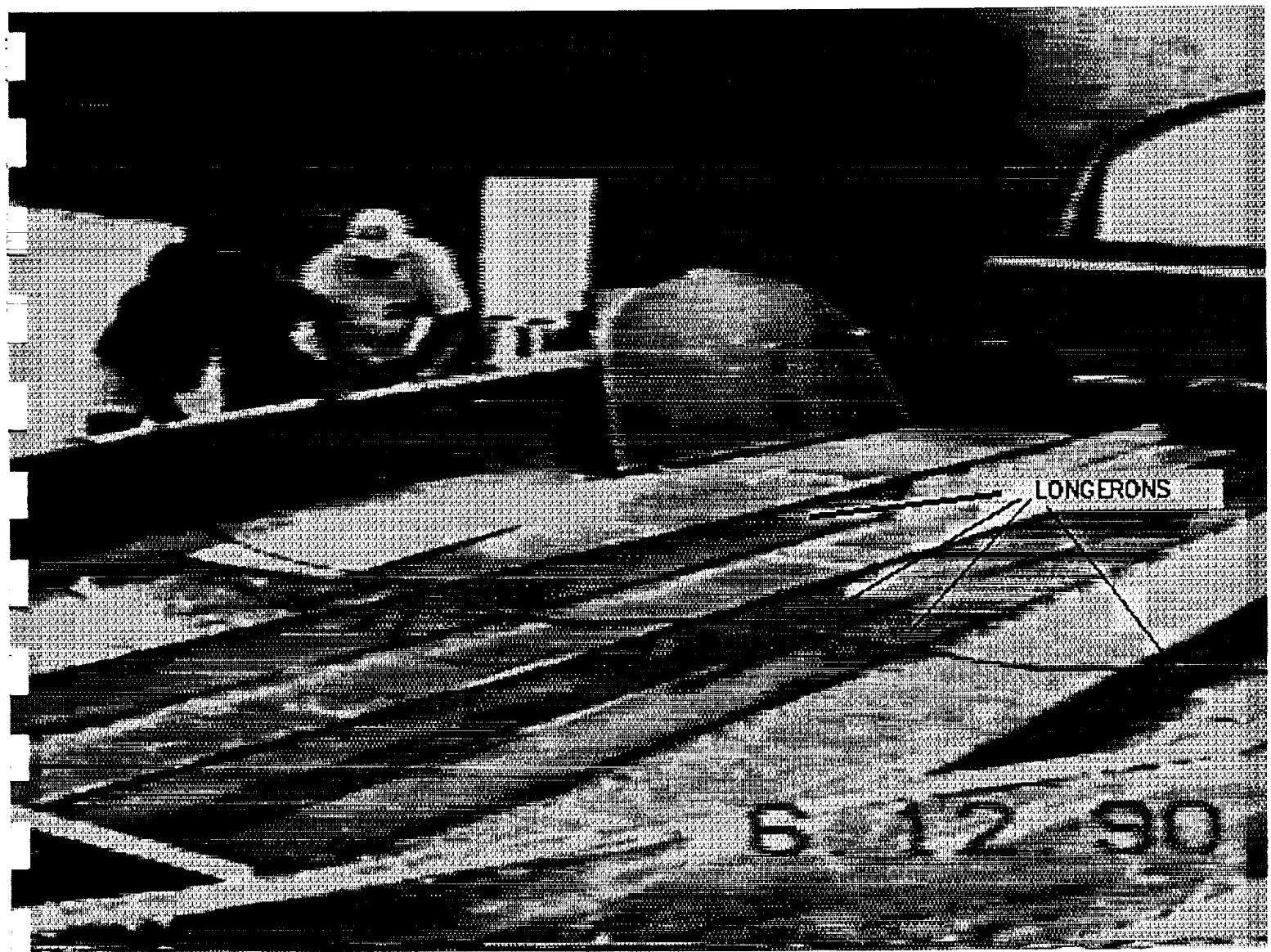


FIGURE 22 - LONGERON INSTALLATION

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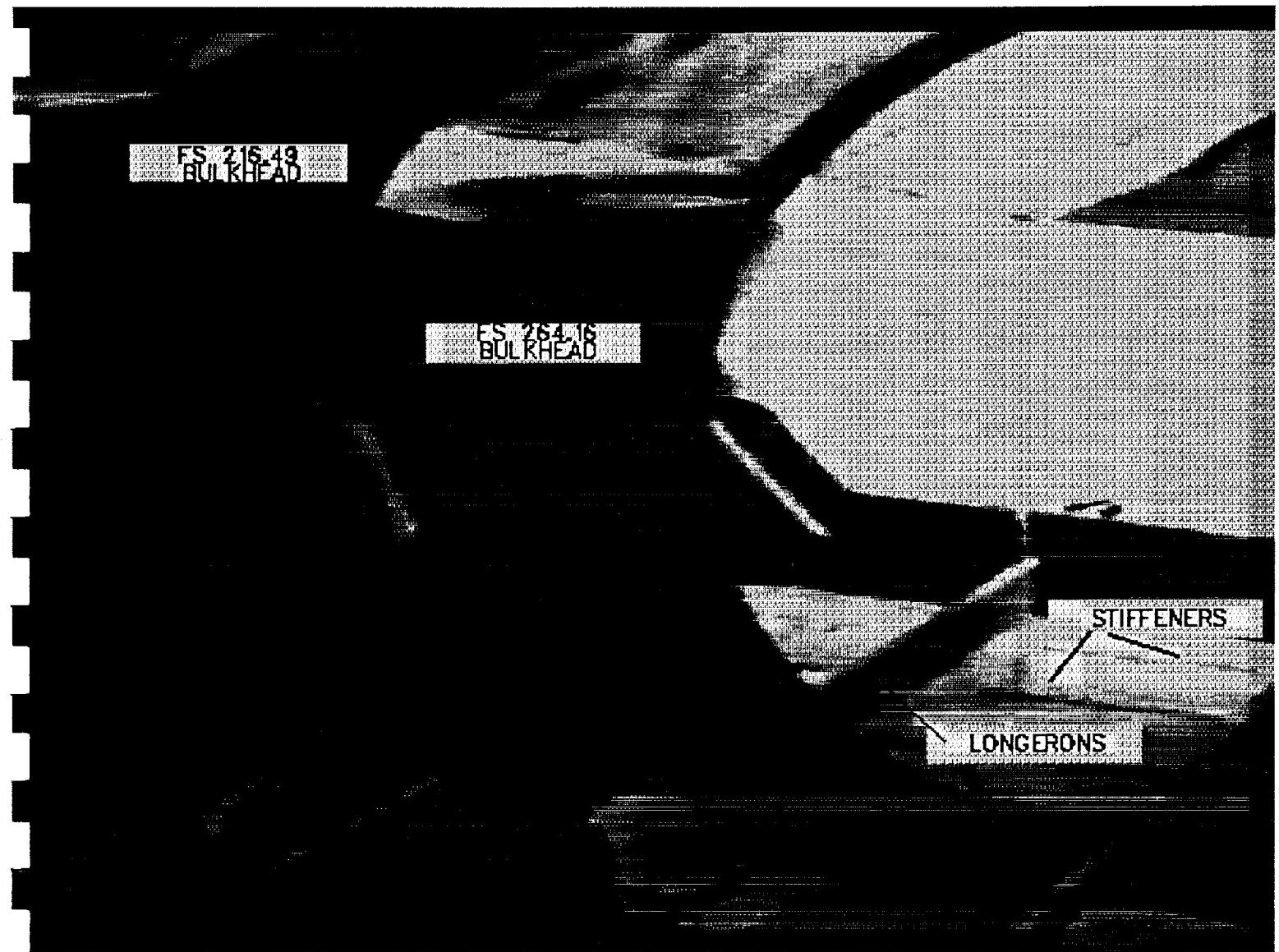


FIGURE 23 - INTERNAL STRUCTURE DETAILS

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**Personnel Launch System
Full-Scale Engineering Model**

LONGERON STRUCTURE

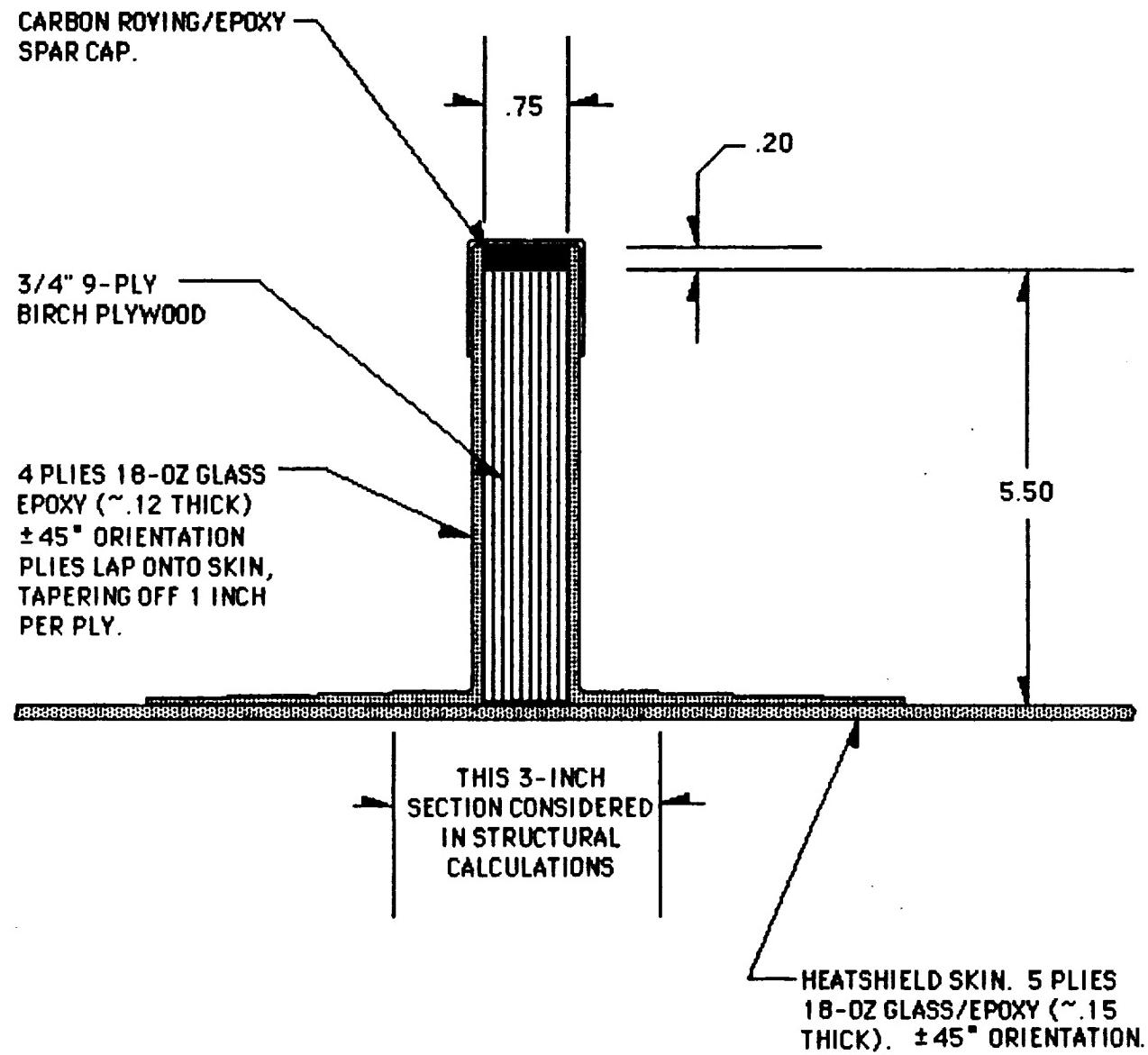


FIGURE 24 - LONGERON STRUCTURE

Personnel Launch System Full-Scale Engineering Model

LOWER MAIN GEAR BULKHEAD STRUCTURE

Typical of the carry-through sections of the FS 216 and FS 264 bulkheads.

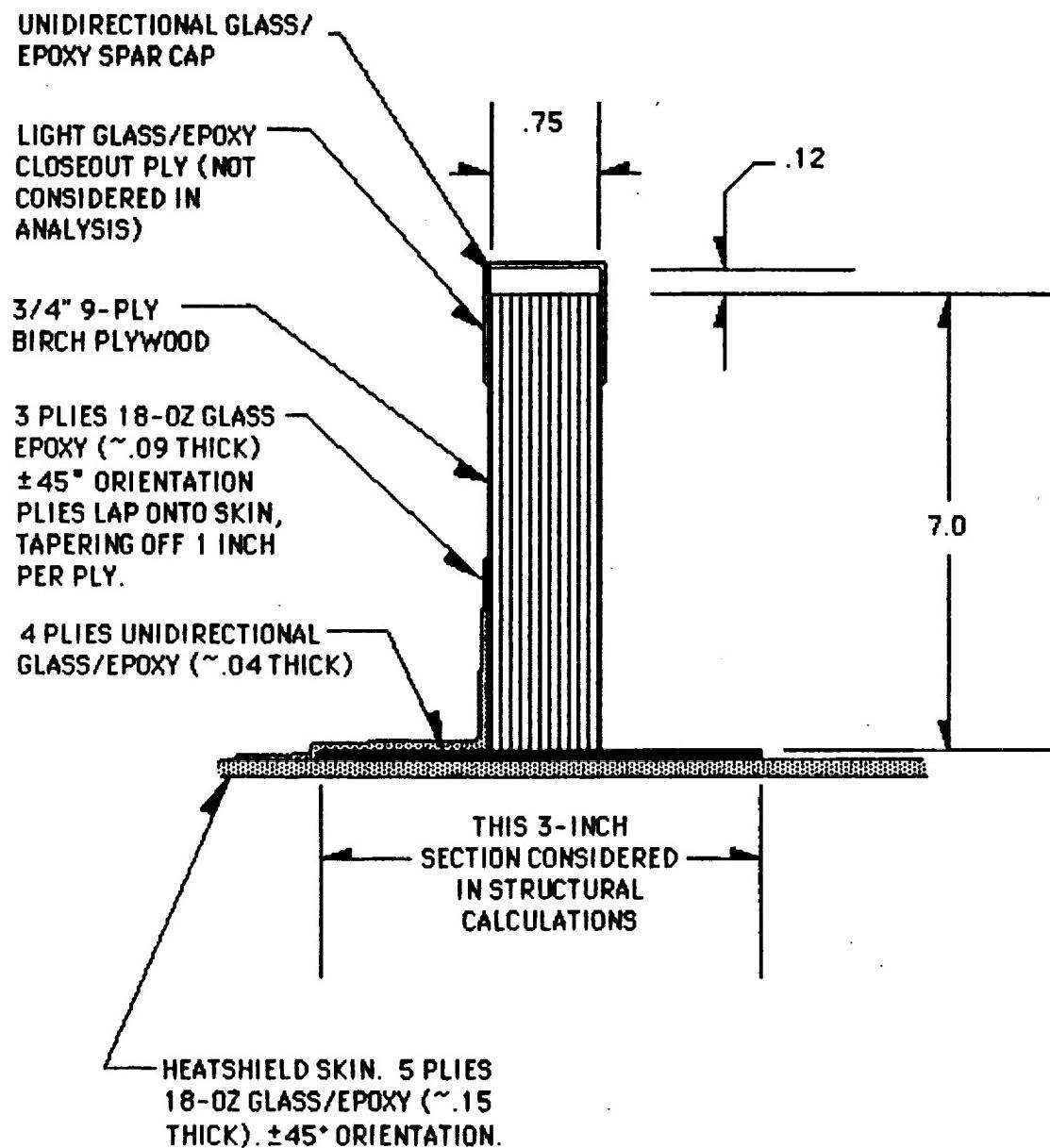


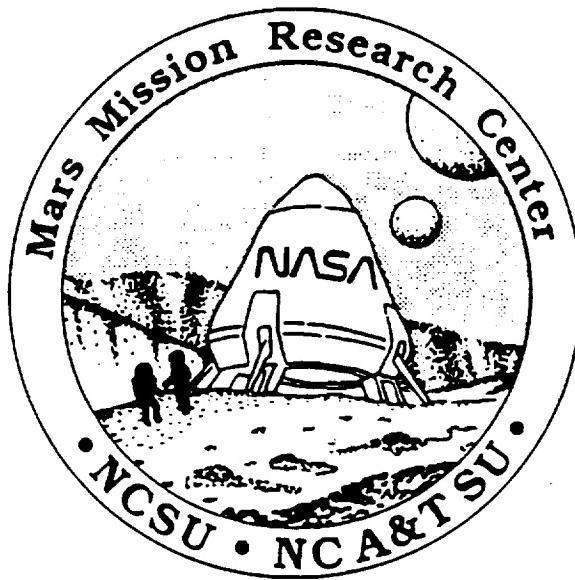
FIGURE 25 - LOWER MAIN GEAR BULKHEAD STRUCTURE

APPENDIX B - DESIGN AND FABRICATION PROPOSAL

PERSONNEL LAUNCH SYSTEM MOCKUP

Design and Fabrication Proposal

March 23, 1990



Presented by
North Carolina State University
Mechanical and Aerospace Engineering

OUTLINE

1. Objectives and Requirements - R. Vess
2. Fabrication Procedure - D. Driver
3. Geometric Manipulation - J. Hickam
4. Structural Design / Analysis - D. Driver
5. Proposed Schedule - R. Vess
6. Transportation Cradle Design - J. Hickam

PLS MOCKUP KEY OBJECTIVES

1. Internal Volume

- Equipment layout
- Provisions
- Habitability

2. Crew Ingress/Egress

- Launch Attitude
- Runway Attitude
- Deconditioned State

3. Maintenance

- Accessibility
- Component Layout

OBJECTIVES, Cont.

4. Vehicle Operations

- Size and Shape
- Visibility
- Overall Handling

5. Display

- Public Relations
- Marketing

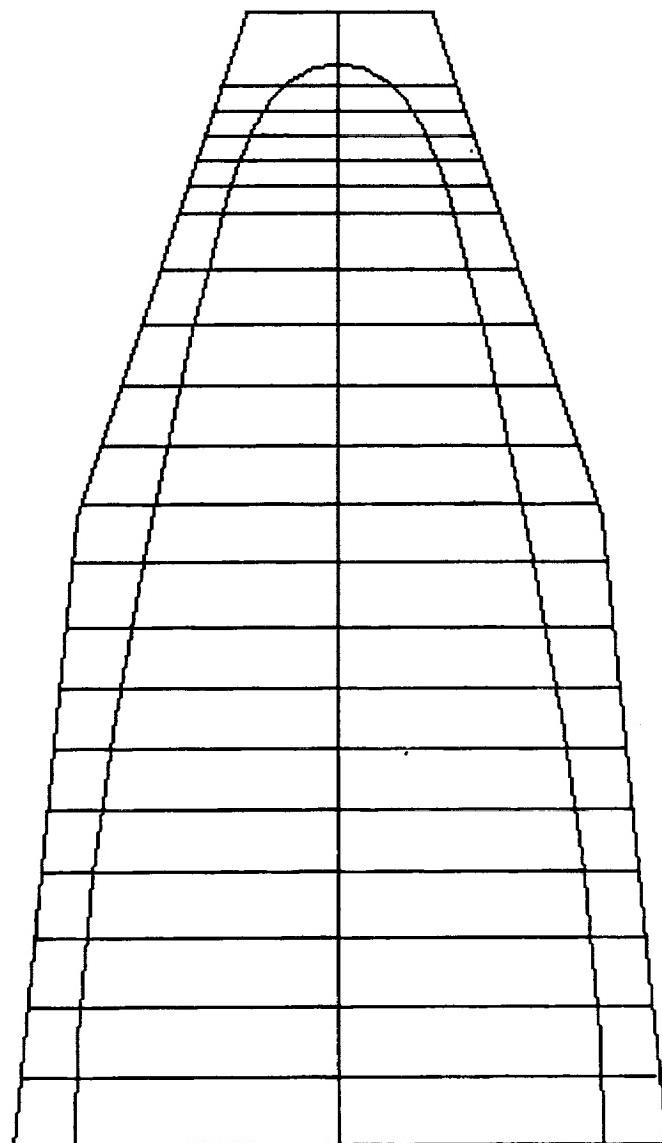
PLS MOCKUP REQUIREMENTS

- Accurate Exterior Geometry
- Open Interior Volume
- Large Removable Panels
- Accommodate 10 people (95%)
- Launch and Landing Attitude
- Top Access Hatch
- Versatile Interior Hard Points
- Rear of Vehicle Open
- Hard Points for Lifting Vehicle
- Durable Structure
- Landing Gear
- Windows Modelled
- Removable Wings/Vertical Tail
- Cradle for Transport

PERSONNEL LAUNCH SYSTEM MOCKUP

Heatshield Fabrication

Lofts are produced for cross sections of the vehicle. From these cuts hotwire templates are made. Female forms are cut from low density stryfoam blocks. Once assembled, these blocks will form a disposable female mold for the heat-shield, requiring little or no hand shaping.



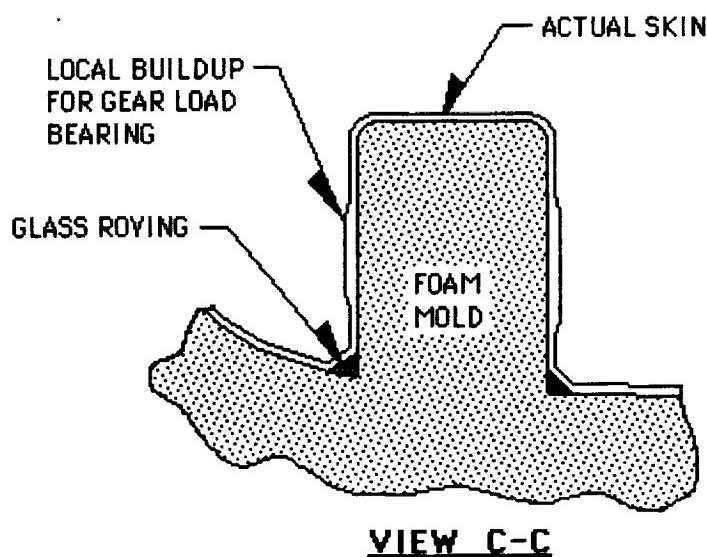
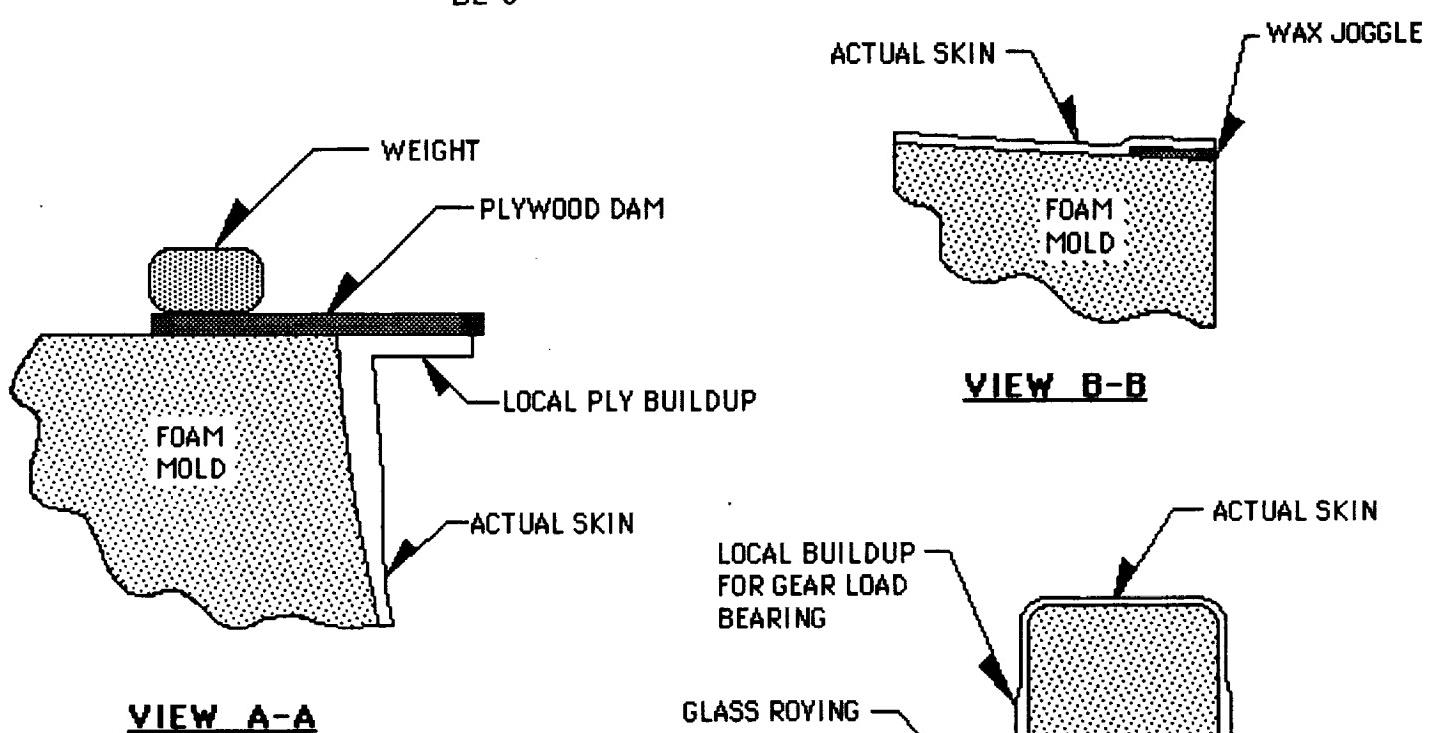
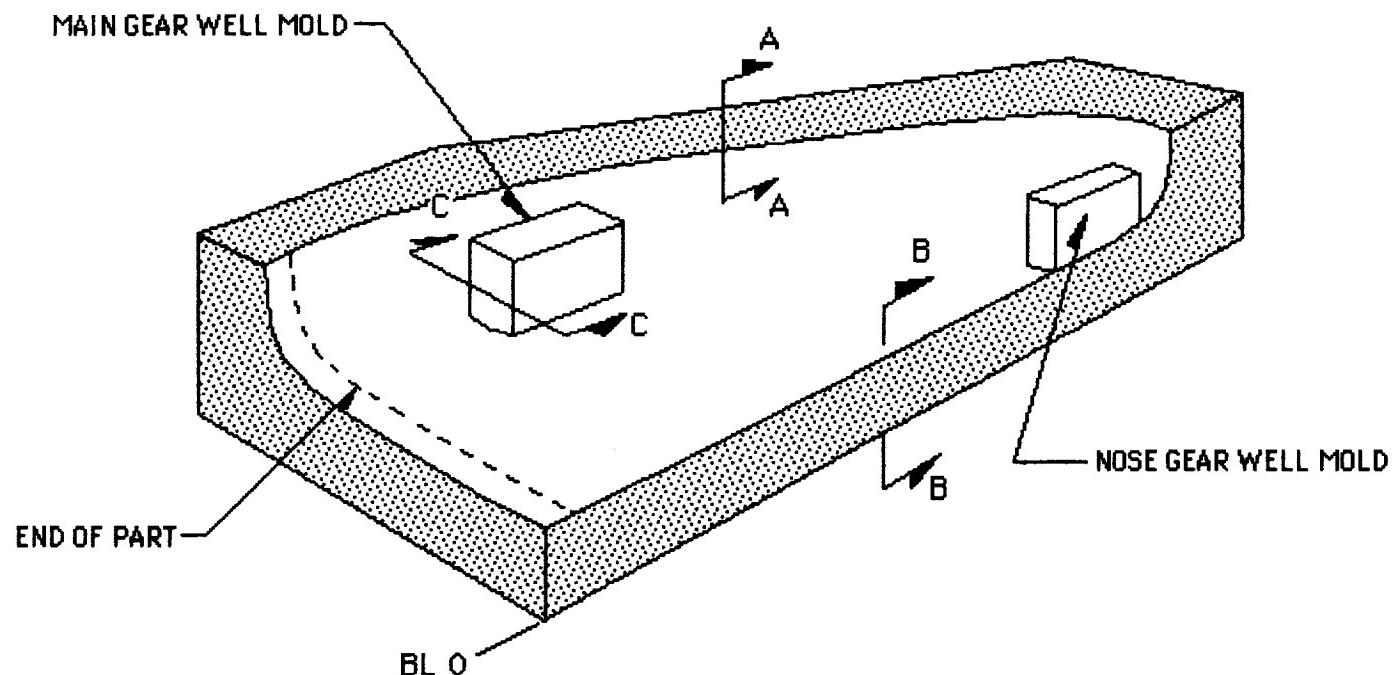
The actual heatshield skin, like all other mockup structure, will be of fiberglass in a matrix of room temperature curing epoxy. To aid in the removal of the part from the mold, a layer of peel ply (dacron cloth) will be placed in the mold before the fiberglass cloth. The peel ply will give the exterior of the heatshield a fabric-like texture to which fillers and paint bond well. Since weight is not a great concern on this mockup, the complexity of cutting, shaping, and bonding core materials may be avoided by simply using thicker laminates (~1/8"). The skins can be made stiffer locally, if required, by later bonding in internal stringers.

Every effort should be made to reduce parts count. For this reason, the three gear wells are molded into the heatshield structure, rather than bonded on later. The gear well molds, like the mold for the entire heatshield, are simple foam blocks hotwired to shape. Local ply buildups are placed where the landing gear will eventually be bolted on. All along the upper edge of the mold, a simply tooled flange will be molded into the part. This flange will mate to a similar one on the upper panels and aid in locating and attaching them. Unidirectional fibers are placed inside the flange to provide overall longitudinal stiffness for the vehicle.

Along the inside edge of the tool, a wax joggle will be added to the mold before layup. This joggle will simulate the thickness of the exterior tapes that will eventually help bond the two halves together. These tapes, then, will be flush with the vehicle surface.

Peel ply will be used on the inside of the layup in areas where bonding will be required later to minimize the work required for surface preparation.

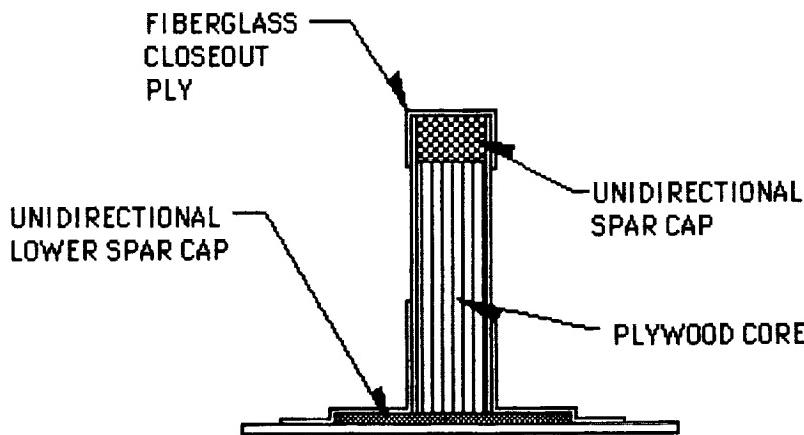
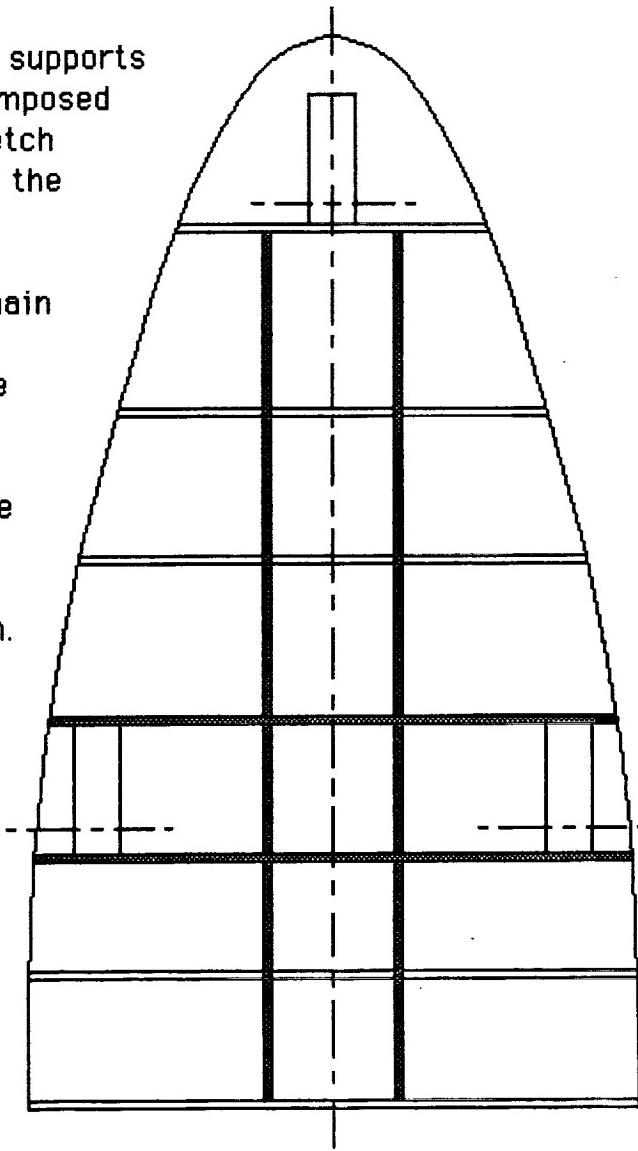
After the layups on each half of the vehicle are completed, the molds will be joined at the centerline and will serve as an assembly fixture for the entire vehicle. Internal glass plies will bond the two skins together. The exterior centerline plies will be added near the end of construction, after the heatshield molds have been removed.



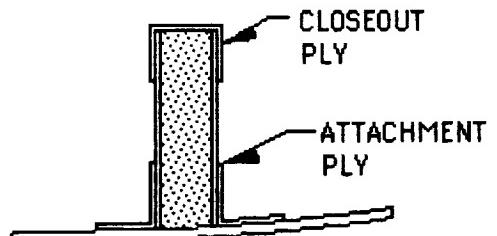
The heatshield skin and its internal supports carry the gear loads and the loads imposed by the equipment and crew. The sketch shows the approximate positions of the stiffening members.

The two ribs running between the main gear wells are designed to carry all main gear loads. Due to the relative position of the gear bearing point, the aft rib carries 75% of the gear load, and the forward rib carries the remainder. The other lateral supports provide stability to the heatshield skin and are of lighter design.

The two longitudinal stiffeners are intended to carry all seat loads into the heatshield skin. These supports are stiff in bending to minimize the tendency for the members to debond from the skin.



HIGHLY LOADED STIFFENER
(Typical of shaded members)



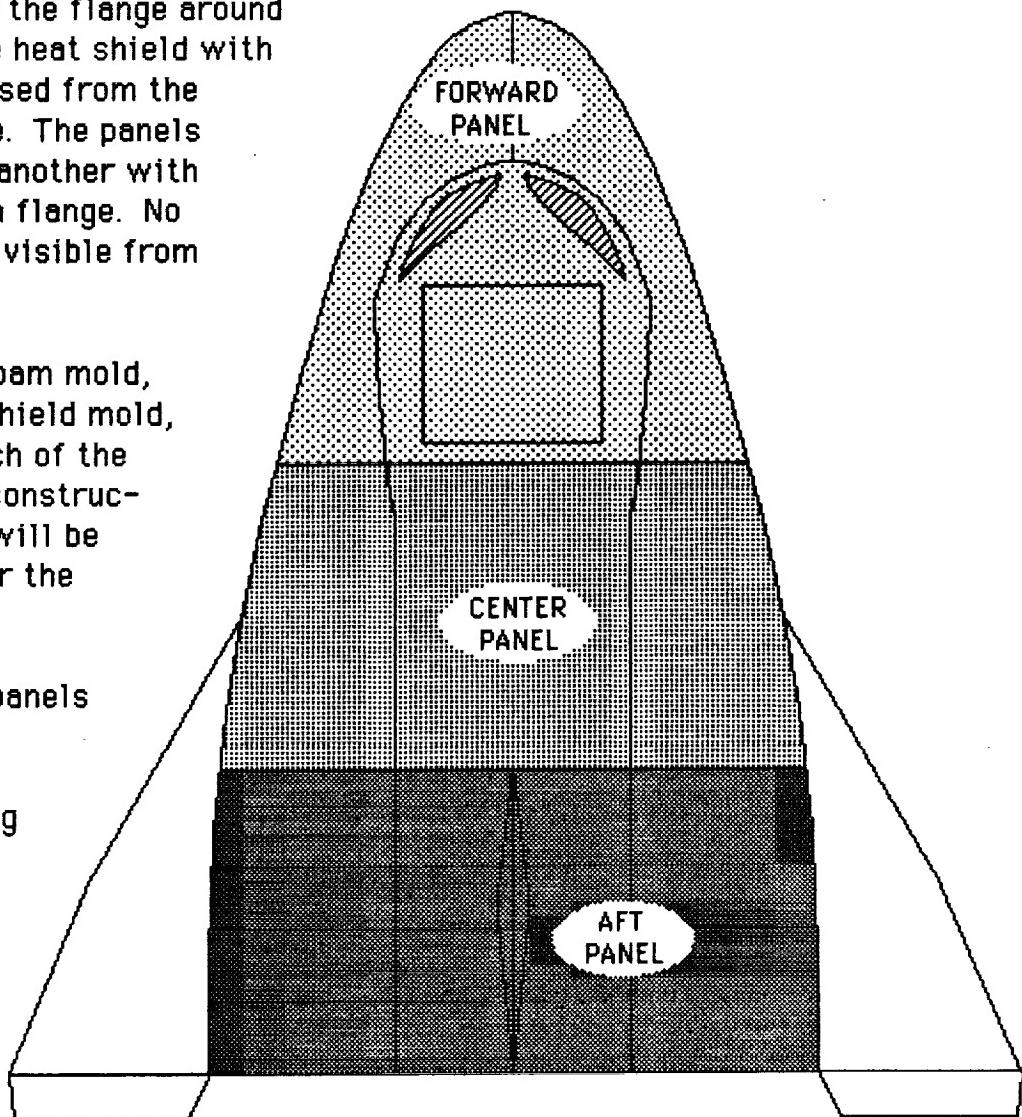
LIGHTLY LOADED STIFFENER
(Typical of unshaded members)

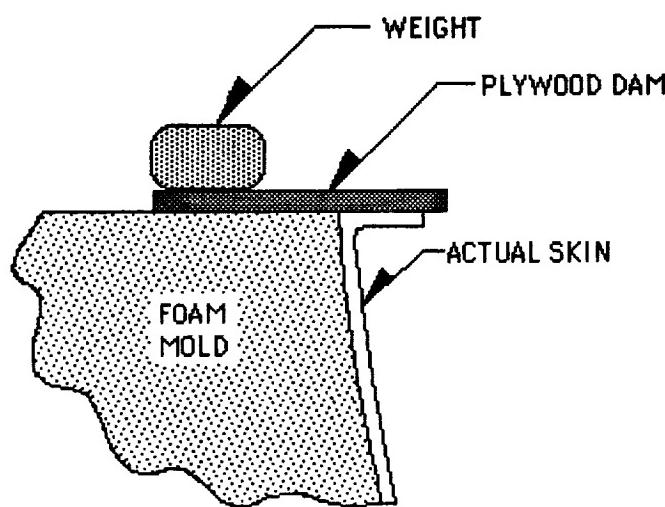
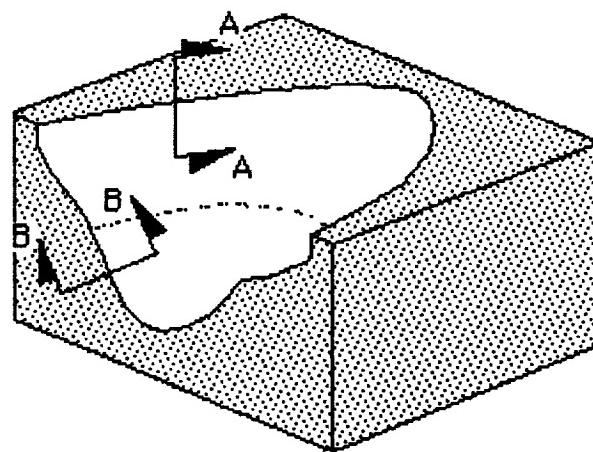
Upper Access Panels

The entire upper surface of the mockup is divided into three large, removable panels. The panels mount to the flange around the perimeter of the heat shield with bolts that are accessed from the inside of the vehicle. The panels are attached to one another with a similar, molded-in flange. No fasteners, then, are visible from the outside.

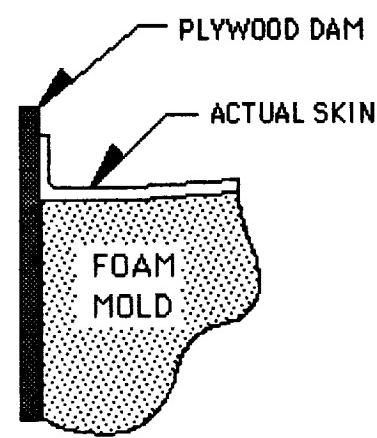
A disposable styrofoam mold, similar to the heatshield mold, will be made for each of the three panels. Mold construction and part layup will be the same as that for the heatshield.

A larger number of panels than shown may be desirable due the difficulty in handling the large parts (the aft panel would weigh about 200 lb). This is left to the customer's discretion.





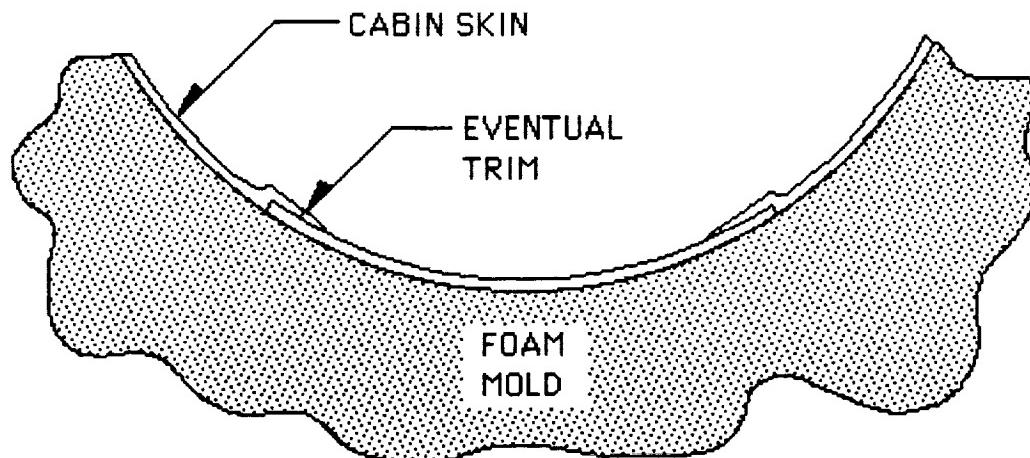
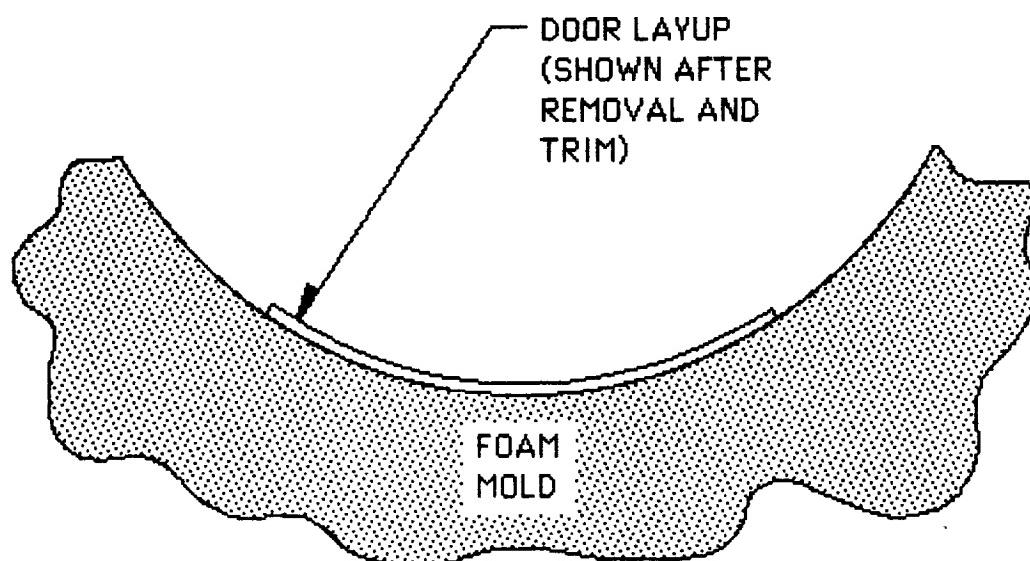
VIEW A-A



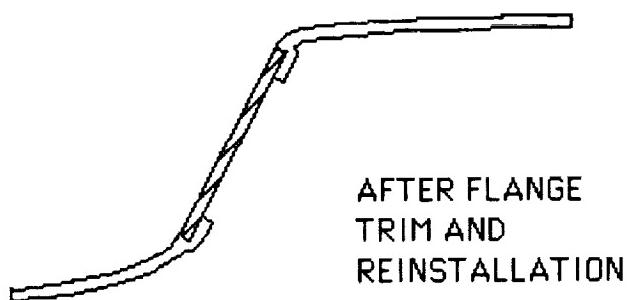
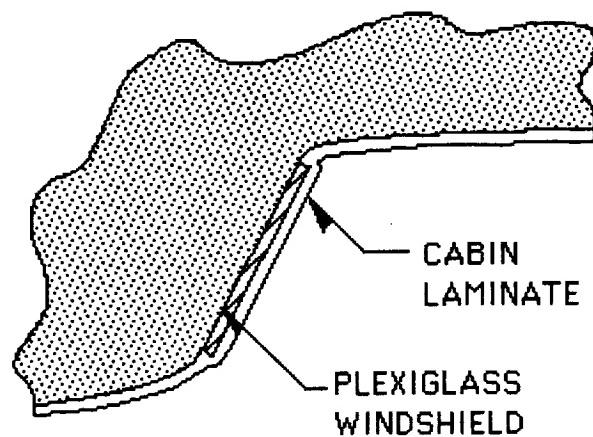
VIEW B-B

The forward panel, like the other two panels, has flanges at all edges. After layup and cure, the panels will be stiffened with glass covered foam strips running laterally and longitudinally along the inside surface.

In order to form a flush fitting door on the top of the cabin, a two step layup is required. The area of the mold that forms the door is covered with a plastic release film, and the door is laid up. After cure, the door is removed and trimmed. The door is placed back in the mold and released on its inner surface. The panel skin is formed over the door. After the entire part is removed from the mold the door flanges are trimmed, and nutplates are mounted.

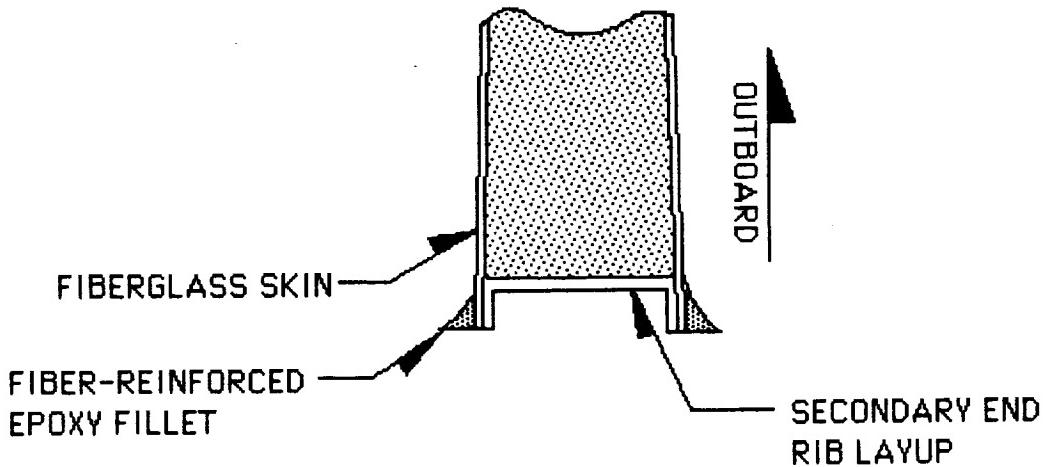
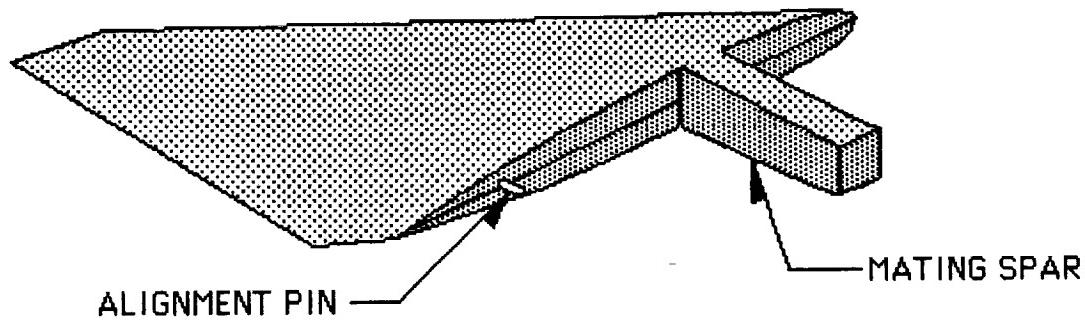


The windshields are molded into the cabin to produce a flush fit. The plexiglass panels are released with wax and placed on the foam mold before the forward panel layup. The layup covers the windows completely. Later, after the part is removed from the mold, the windows are taken out to allow trimming of the flanges. The plexiglass is reinstalled with silicone adhesive.

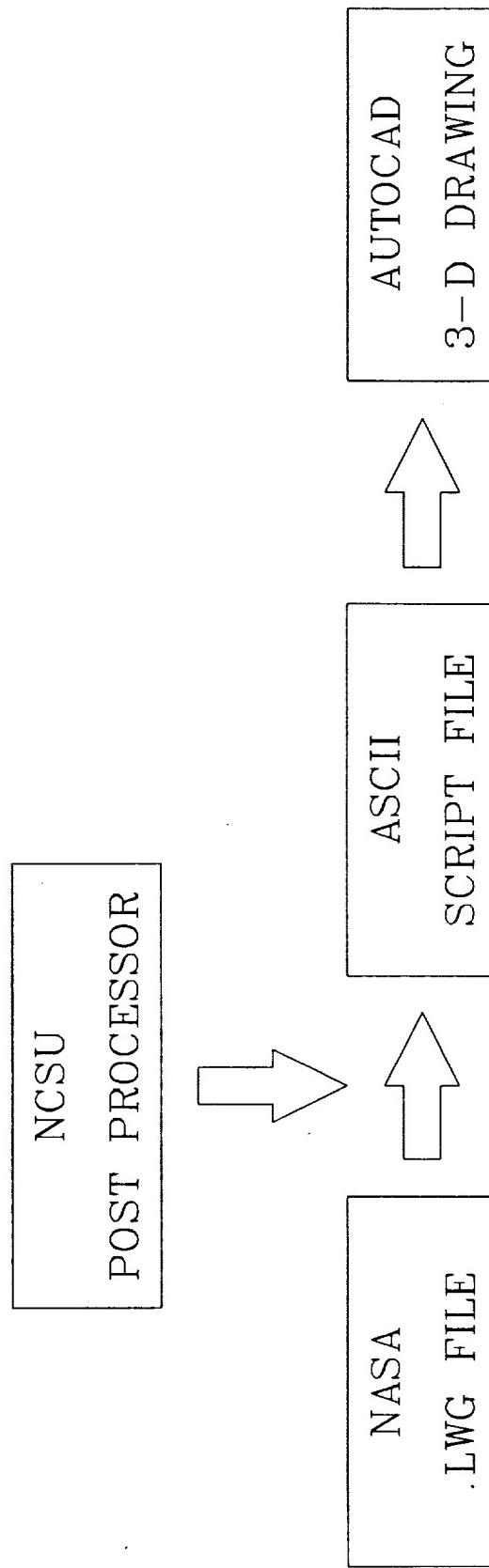


Flying Surfaces

The wings and vertical tail will consist of a hotwired styrofoam core within a fiberglass/epoxy skin. The vertical tail will be permanently attached to the aft upper panel. The wings will have an integral spar protruding from the root which will bolt to the aft main gear bulkhead. A separate pin near the trailing edge will hold the wing at the set incidence. A smooth fillet between the wing root and fuselage will be formed of fiber reinforced epoxy.



PLS GEOMETRIC DATA BASE TRANSFORMATION PROCESS

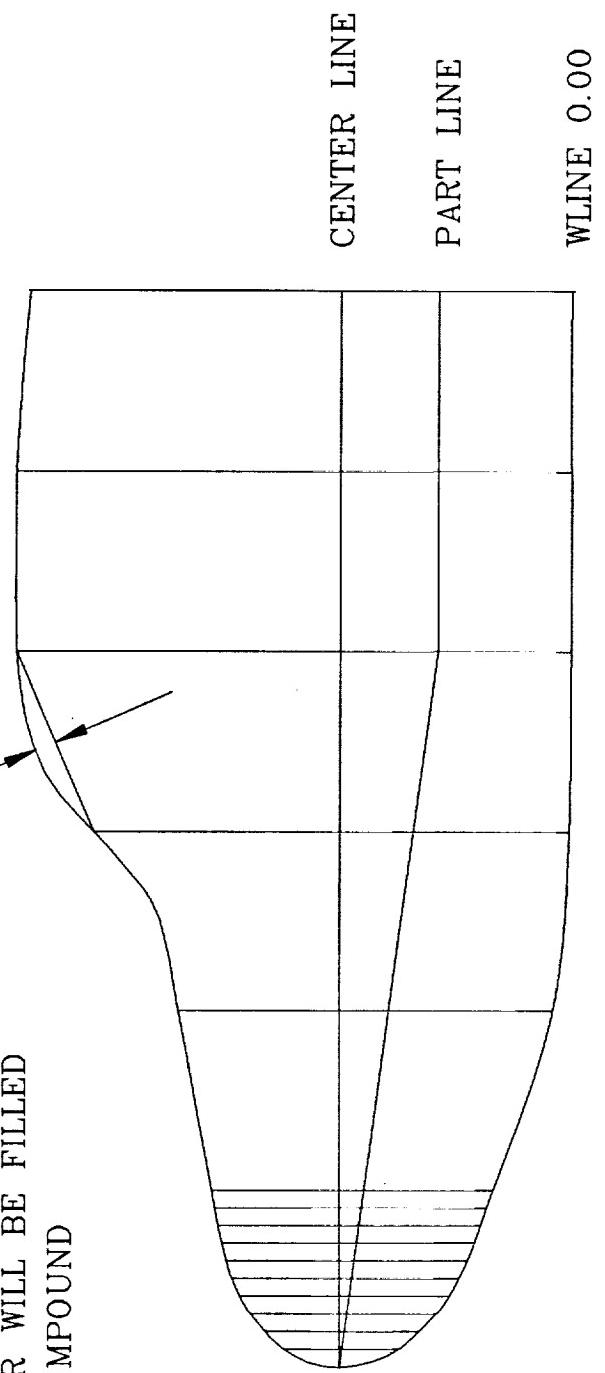


PLS OUTER MOLD LINE ERROR ANALYSIS

TEMPLATES ARE ON 0.10, 0.25, 0.5, 1.0
FOOT LONGITUDINAL SPACING
AS REQUIRED TO MEET TOLERANCE

UNDERCUT ERROR WILL BE FILLED
WITH FAIRING COMPOUND

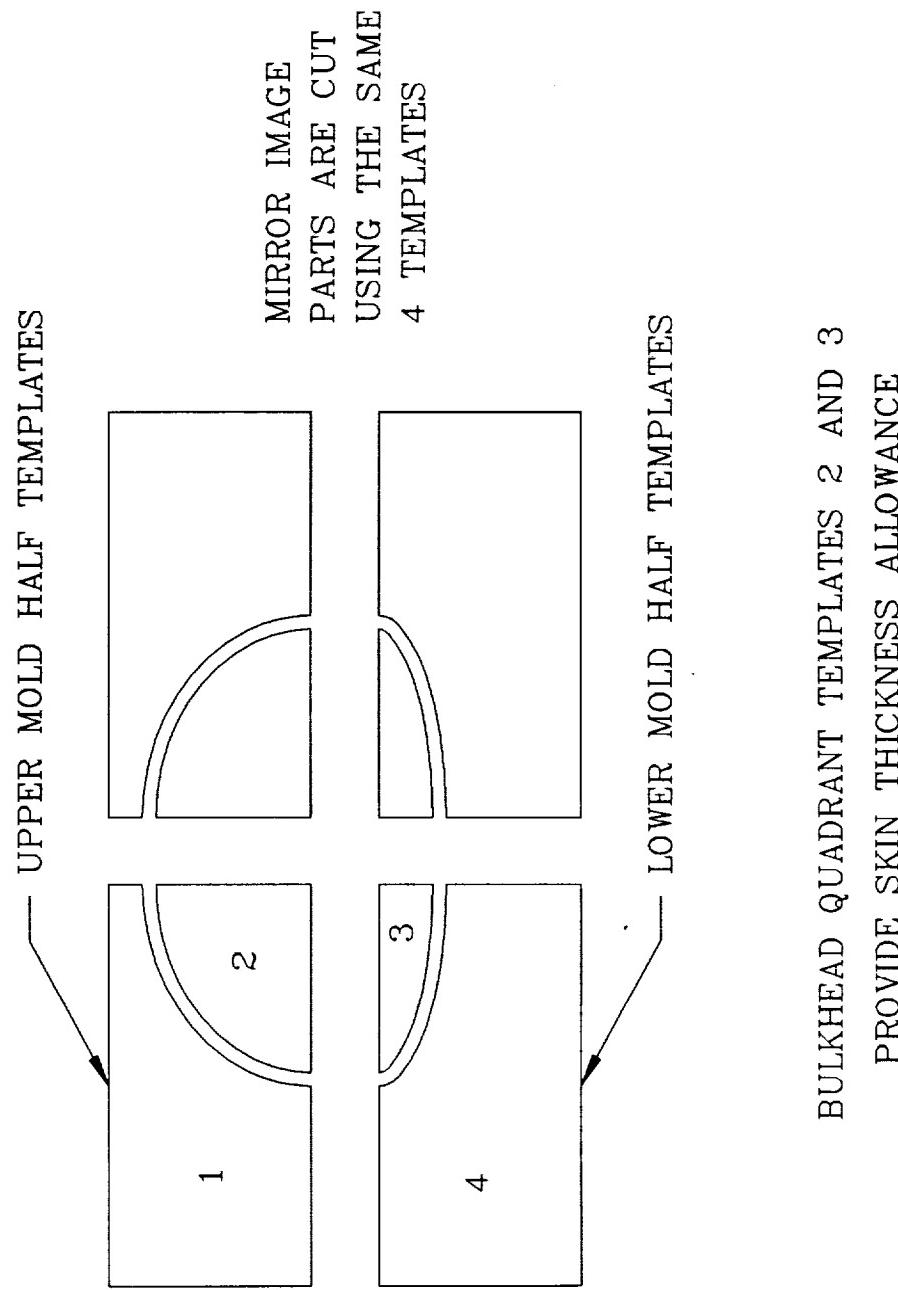
OVERCUT ERROR 0.0 BY DESIGN
UNDERCUT ERROR 0.10 INCHES MAX
(EXAMPLE GROSSLY EXAGGERATED)



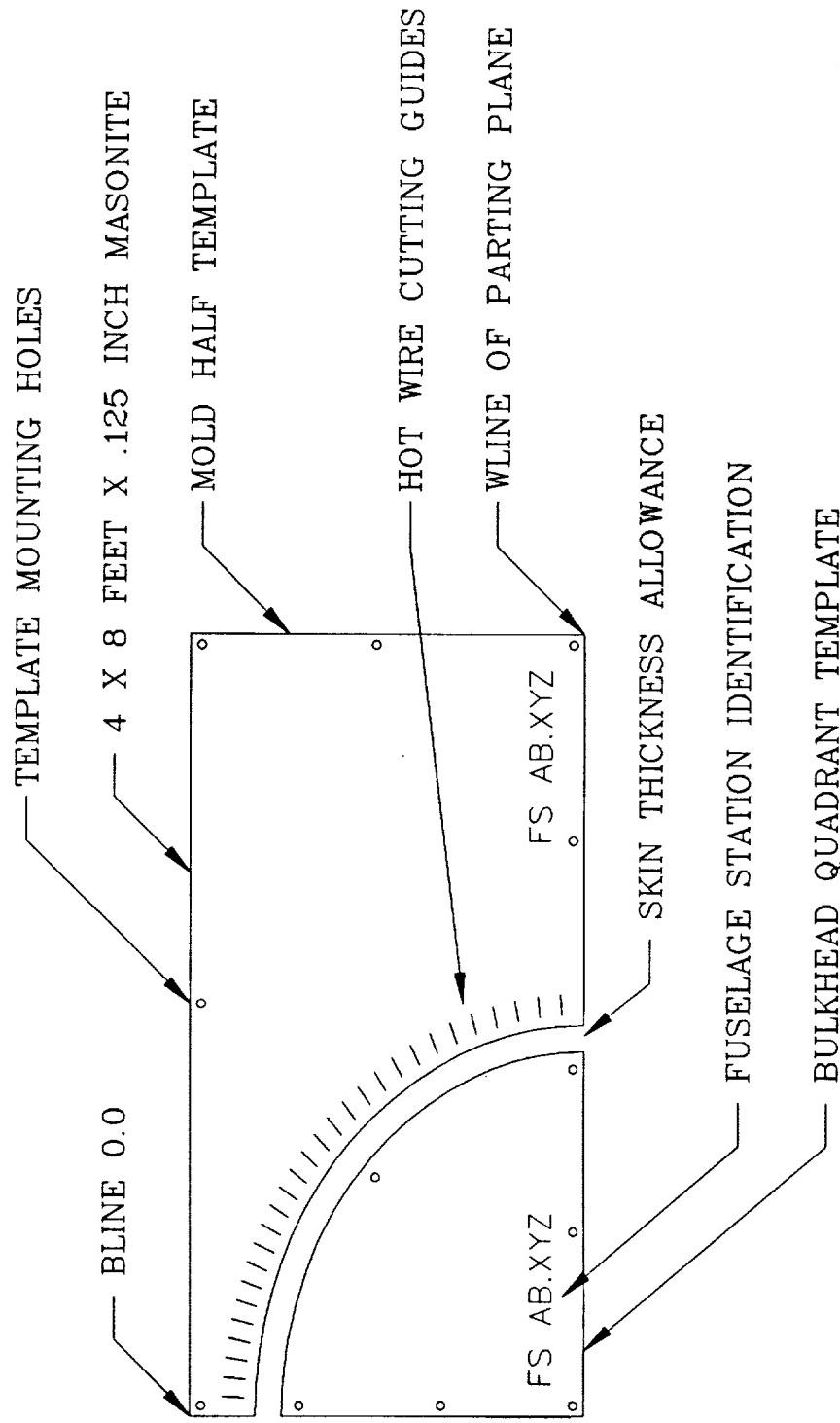
NASA SUPPLIED 90,000 DATA POINTS
COMPRISING 250 FUSELAGE STATIONS

NCSU SELECTED 58 FUSELAGE STATIONS
TO LIMIT DIMENSIONAL ERROR TO 0.10 INCH
FROM TRUE OUTER MOLD LINE

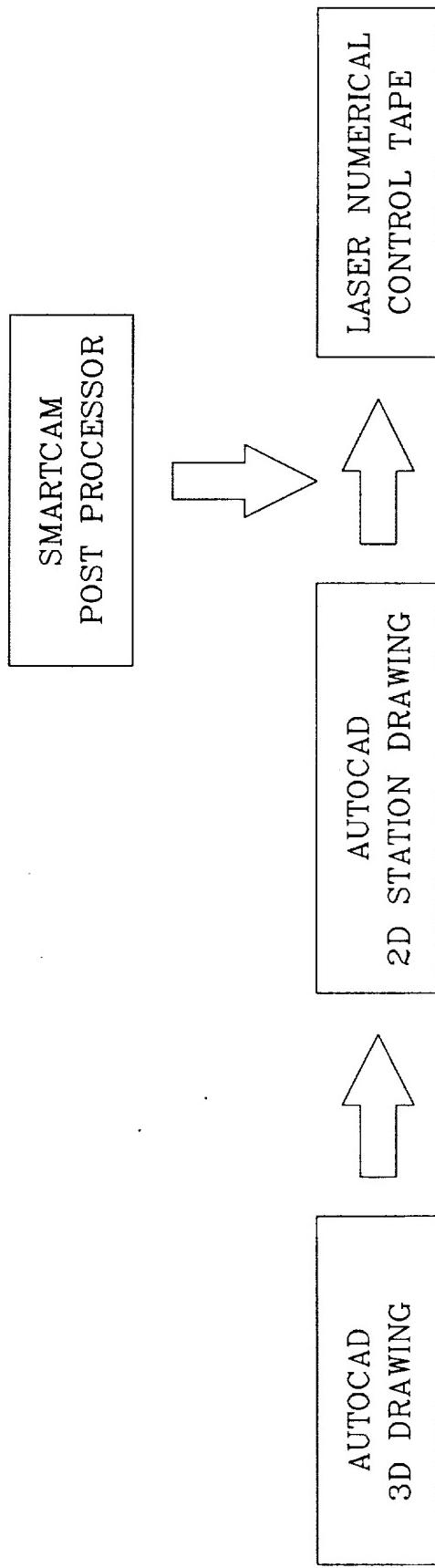
TYPICAL FUSELAGE STATION TEMPLATE REQUIREMENTS



FUSELAGE STATION LASER CUTTING GEOMETRY



COMPUTER INTEGRATED PRODUCTION OF PLATE MOCKUP TEMPLATES



PLS STRUCTURAL ANALYSIS

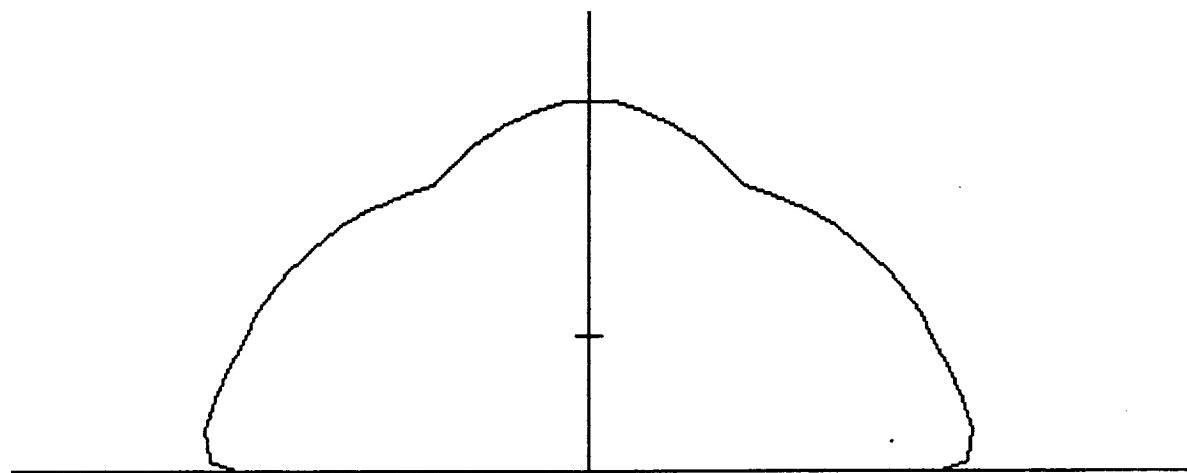
X Station = 183.79 in Skin Thickness = .165 in

Y Centroid = -0.00 in Z Centroid = 26.50 in Skin Area = 61.00 in²

Moment of inertia about Y Axis = 43894.76 in⁴

Moment of Inertia about Z Axis = 137521.2 in⁴

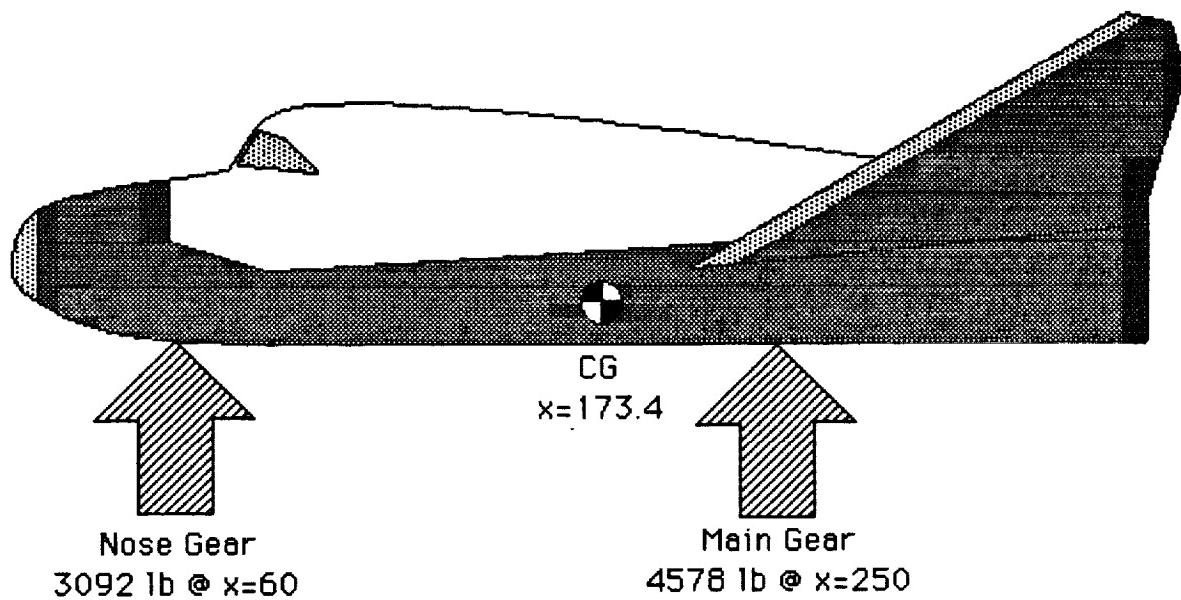
Enclosed Area of Section = 7681.659 in²



Personnel Launch System Mockup

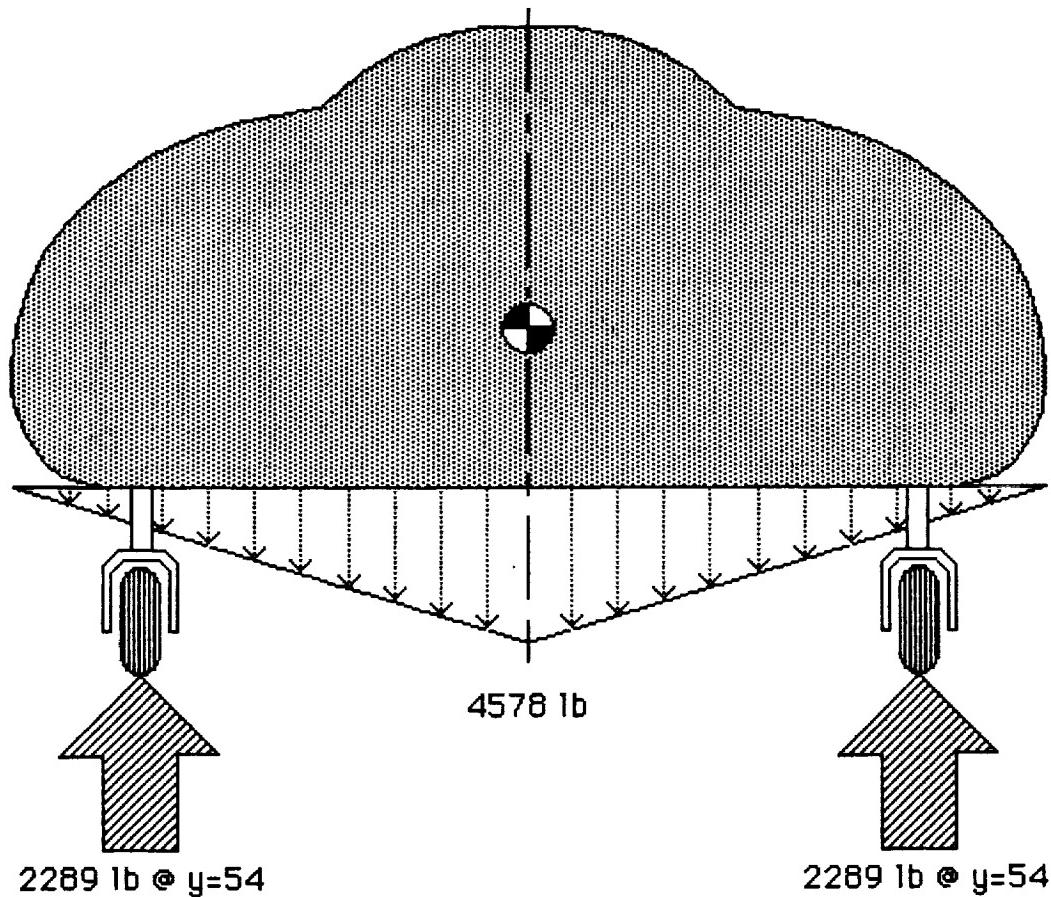
Load Case 1

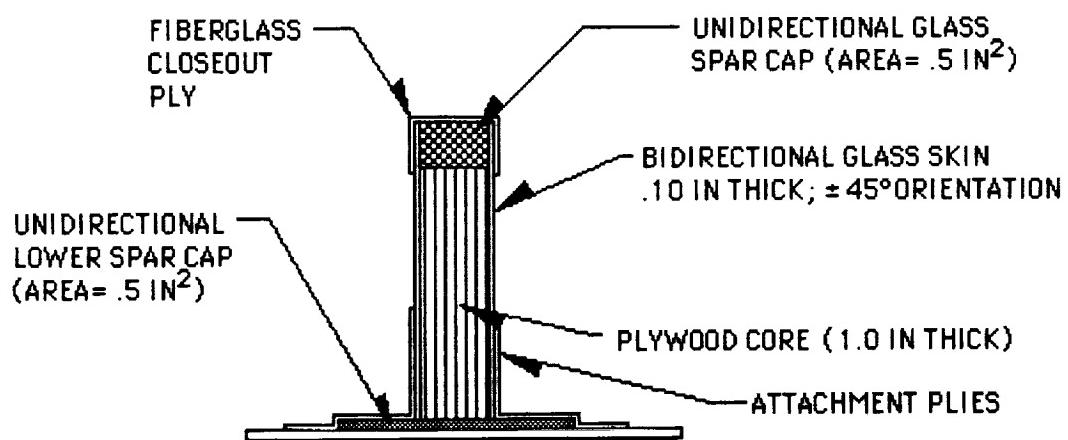
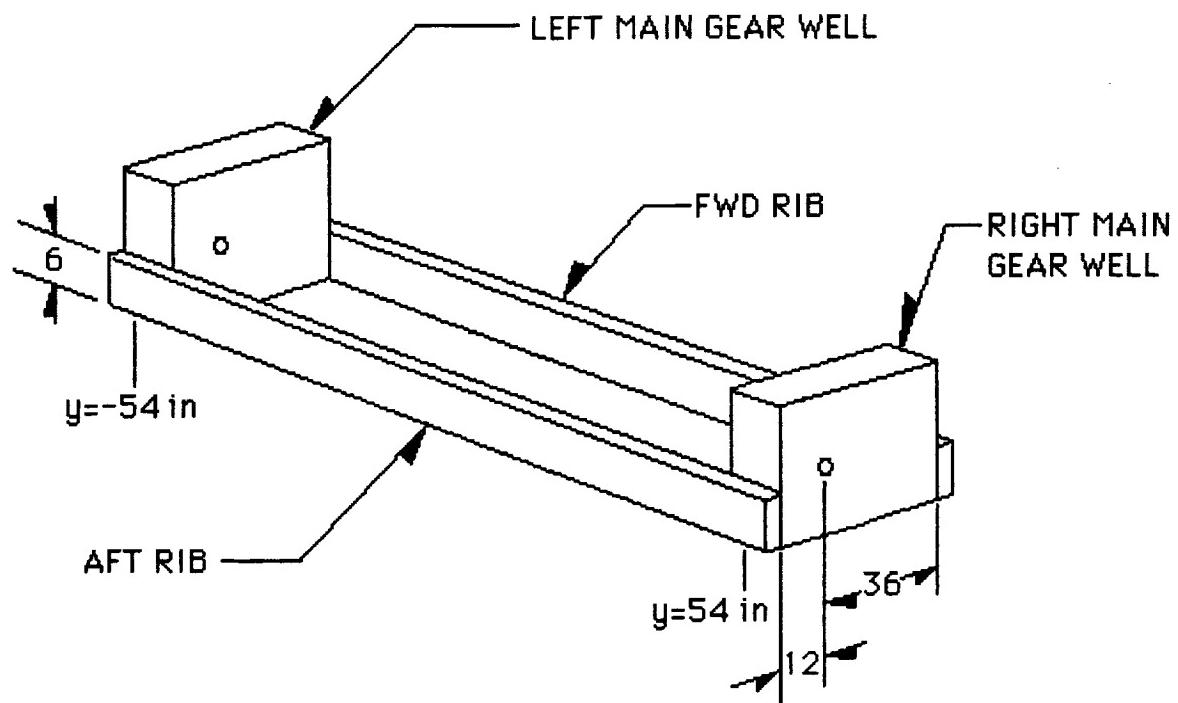
Vehicle fully loaded with 2000 lb of equipment and 2900 lb crew for a gross weight of 7670 lb. At rest on gear on horizontal surface. This case represents the worst case for lateral bending between the main gear.



Load Case 1

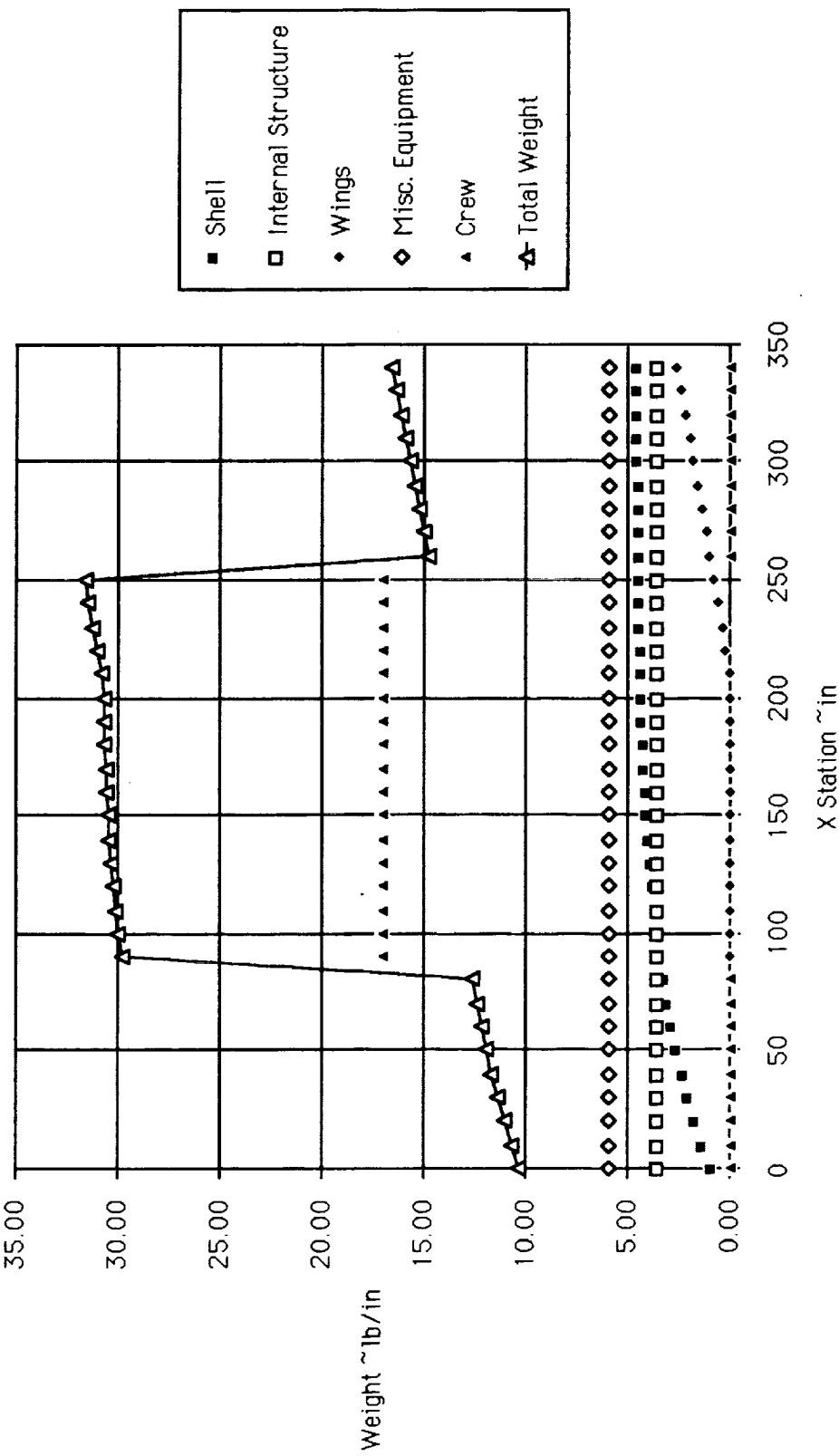
The load case shown schematically below was analyzed to determine the shear and bending stresses on the two ribs supporting the main gear. The load distribution was assumed to be triangular, peaking at the vehicle centerline and tapering to zero at the section maximum width. The two ribs were assumed to carry all the load, though in reality much of the load will be absorbed into the adjacent structure.



Load Case 1 (cont.)

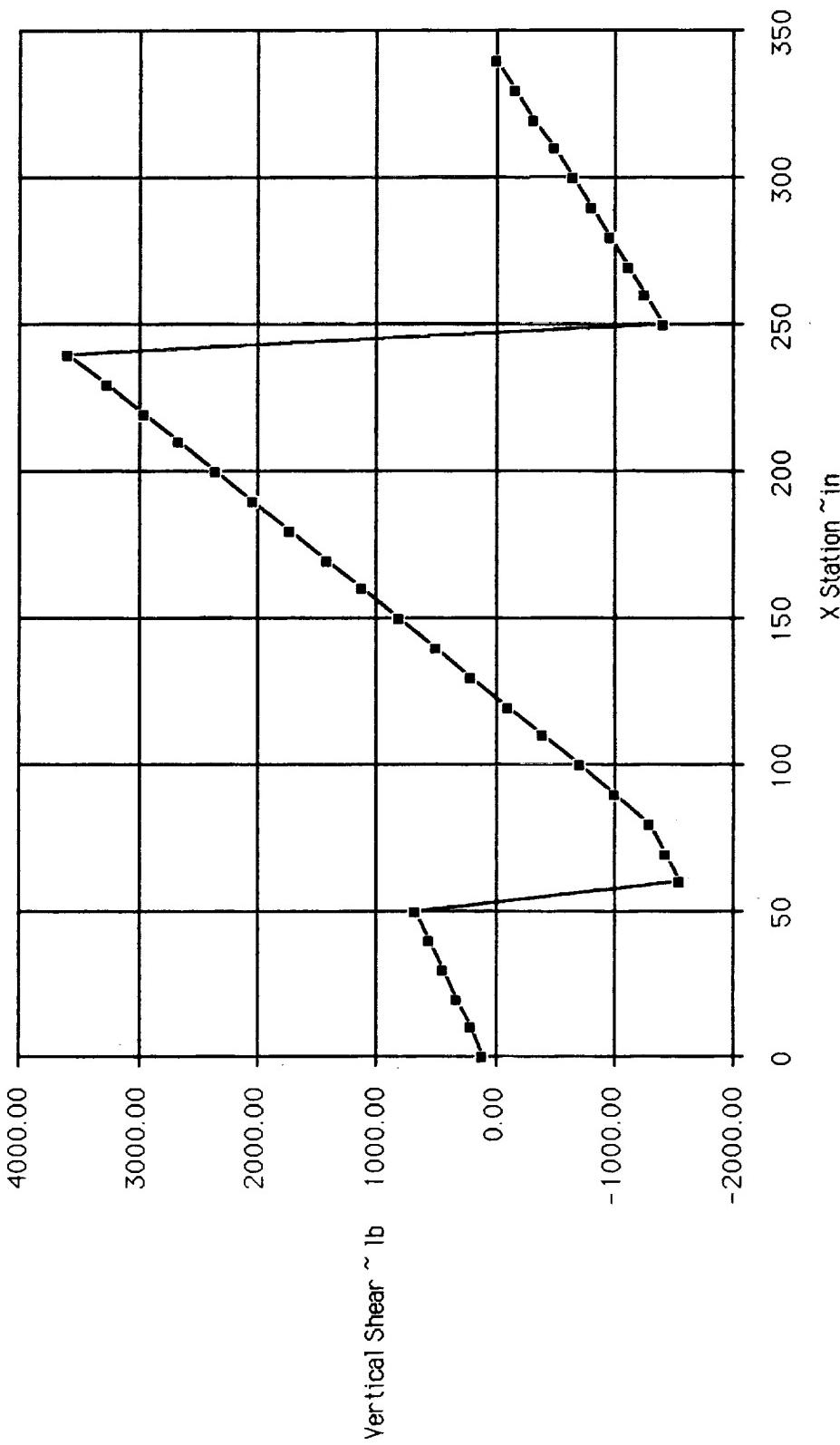
PLS Mockup Weight Distribution

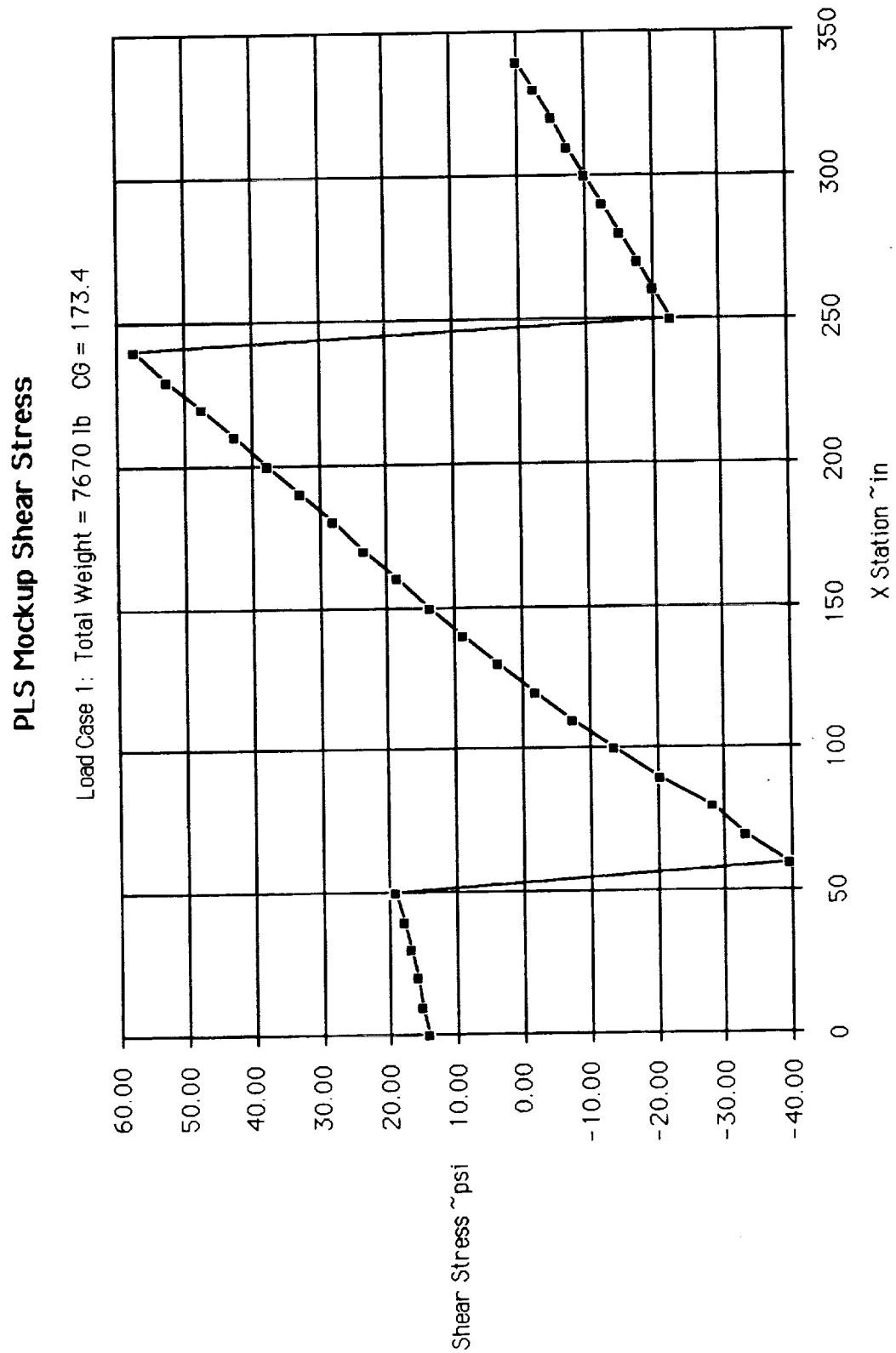
Load Case 1: Total Weight = 7670 lb CG = 173.4

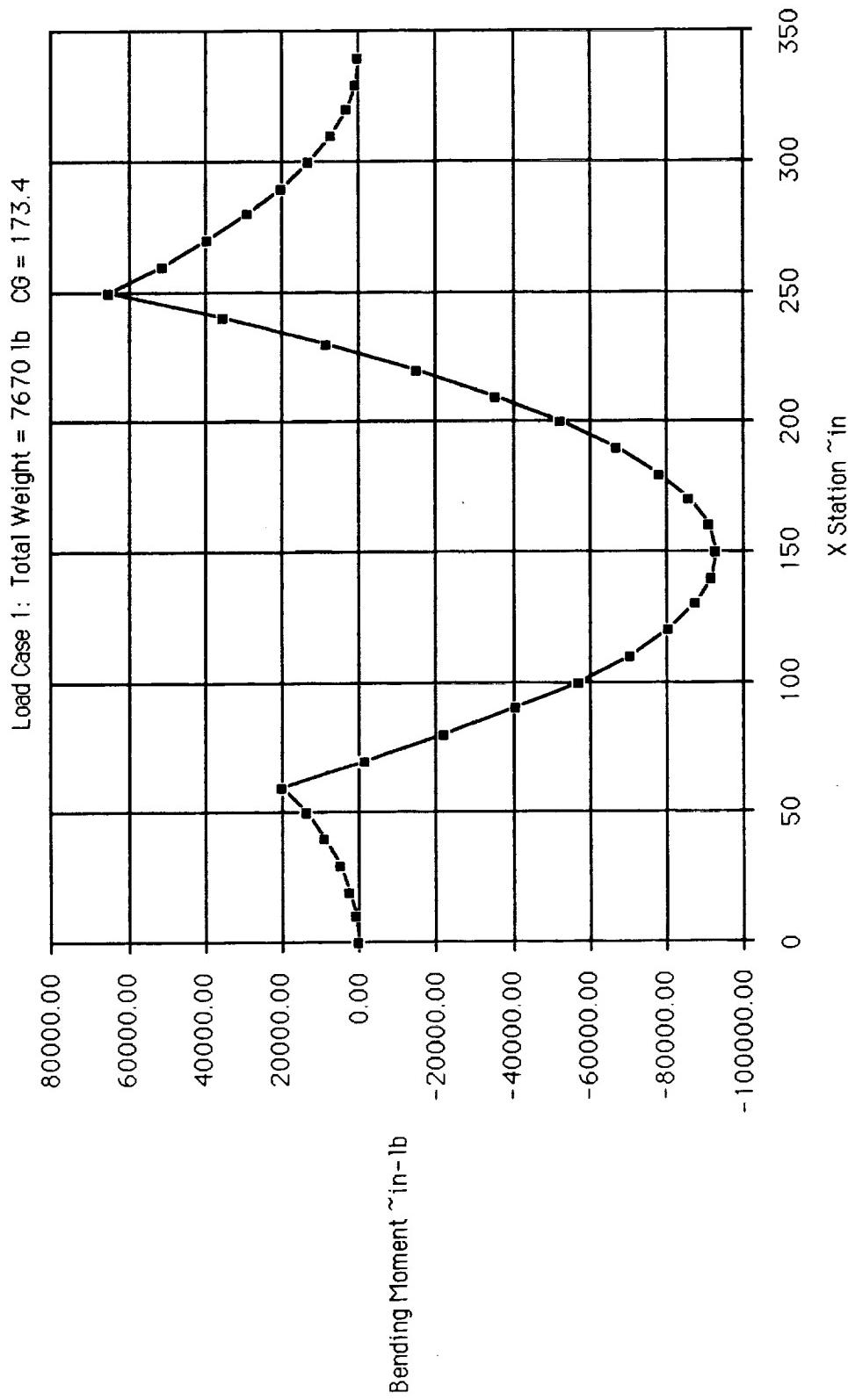


PLS Mockup Vertical Shear Load

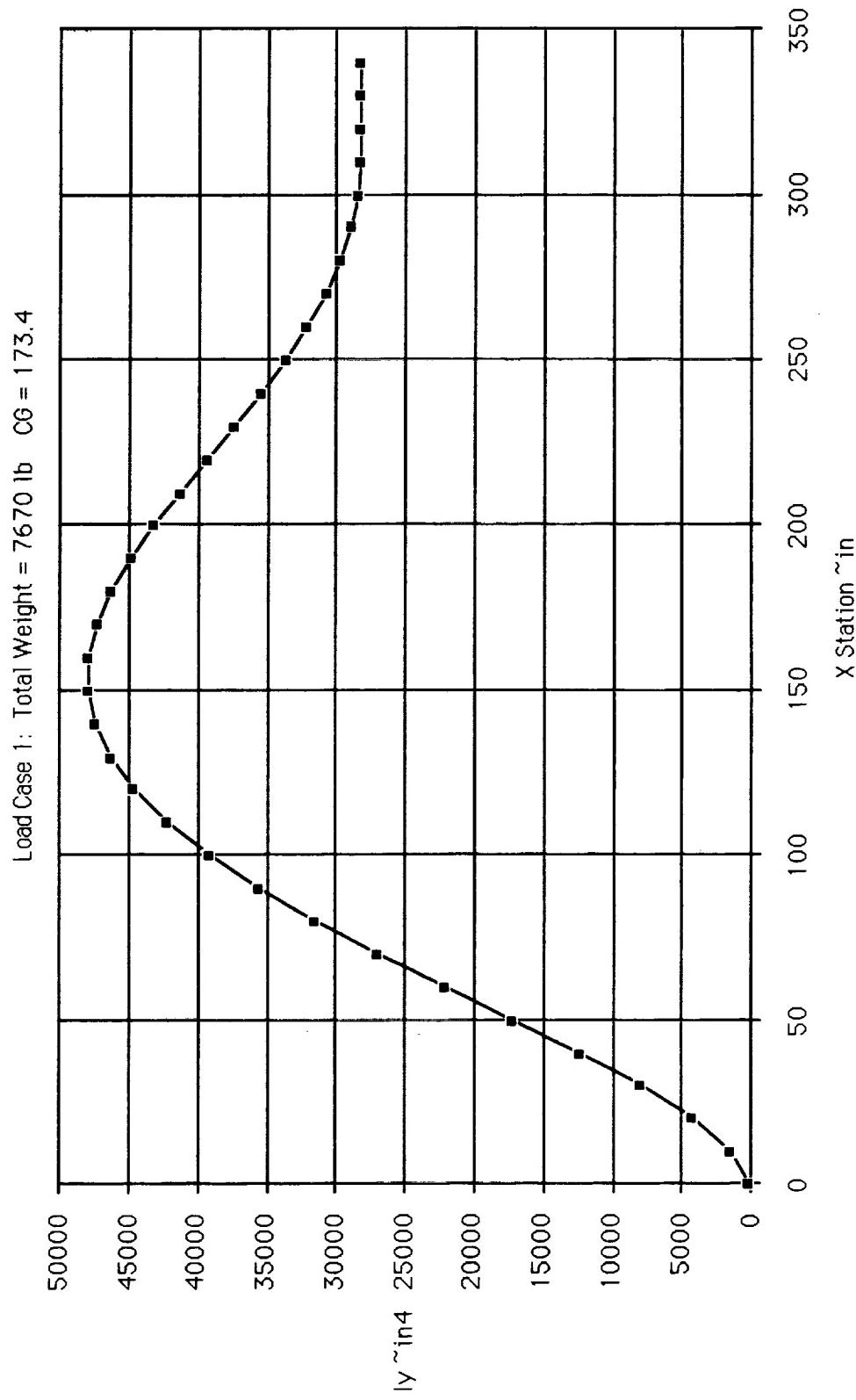
Load Case 1: Total Weight = 7670 lb CG = 173.4





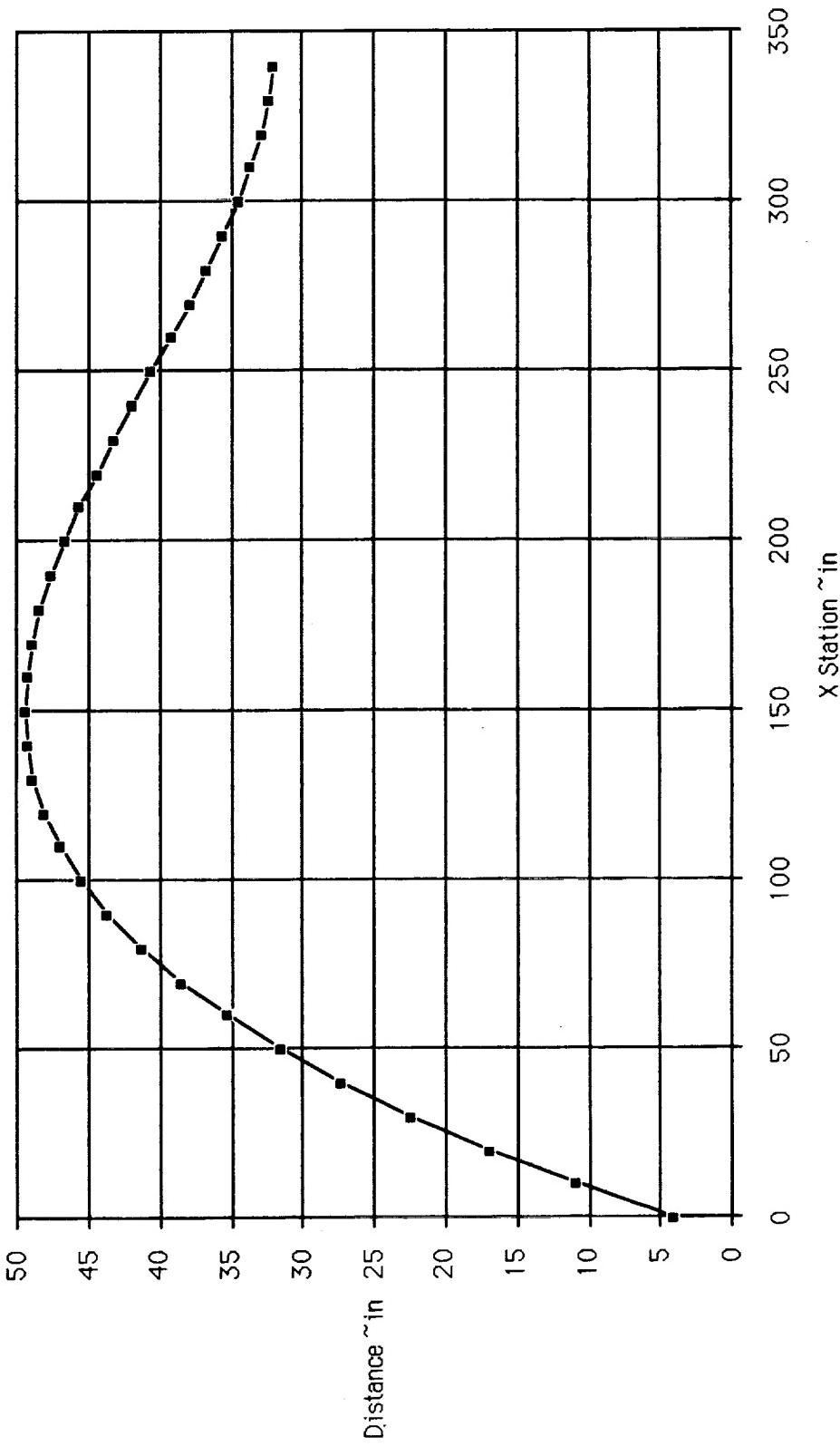
PLS Mockup Vertical Bending Moment

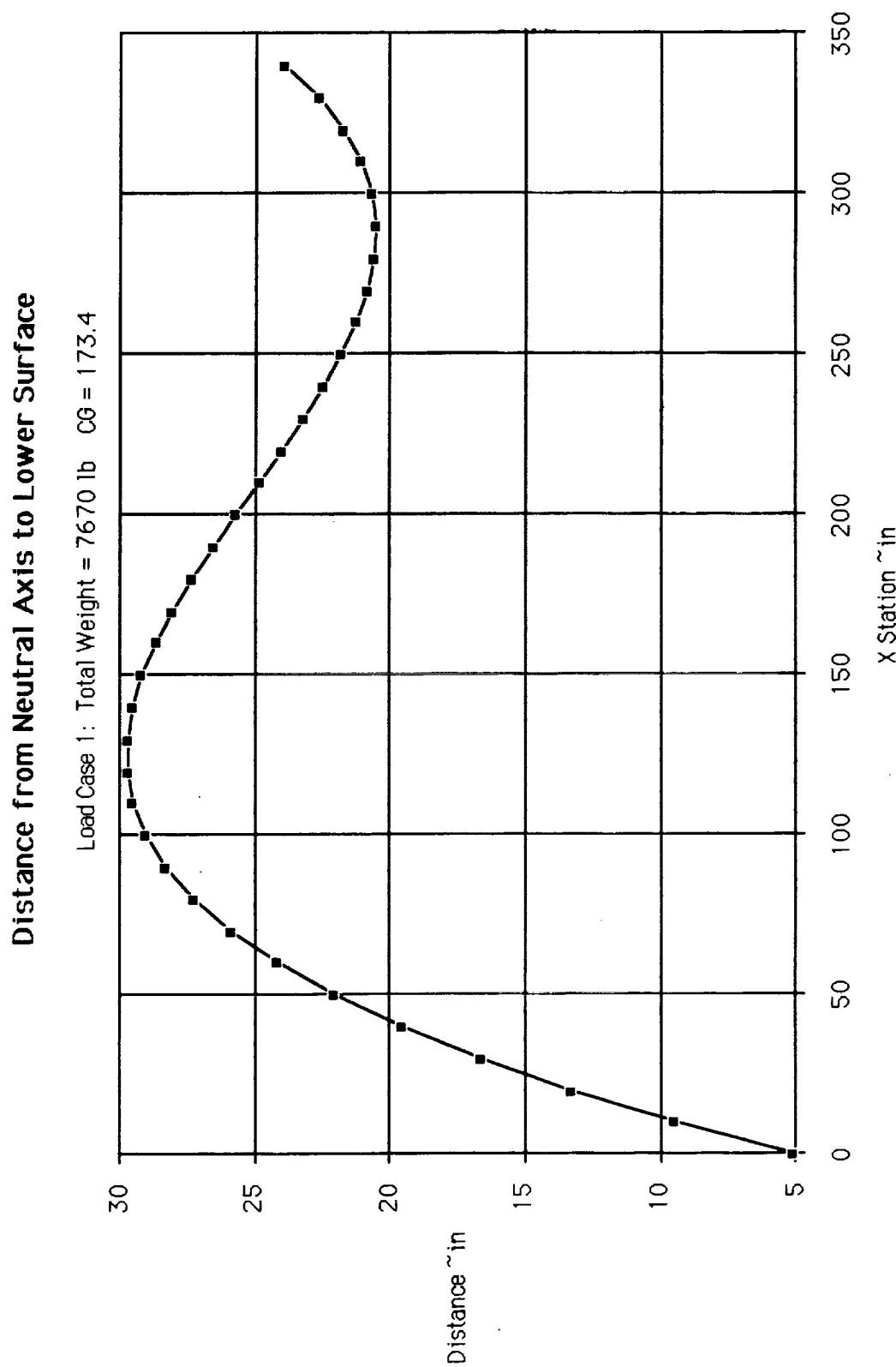
PLS Mockup Vertical Bending Moment of Inertia



Distance from Neutral Axis to Upper Surface

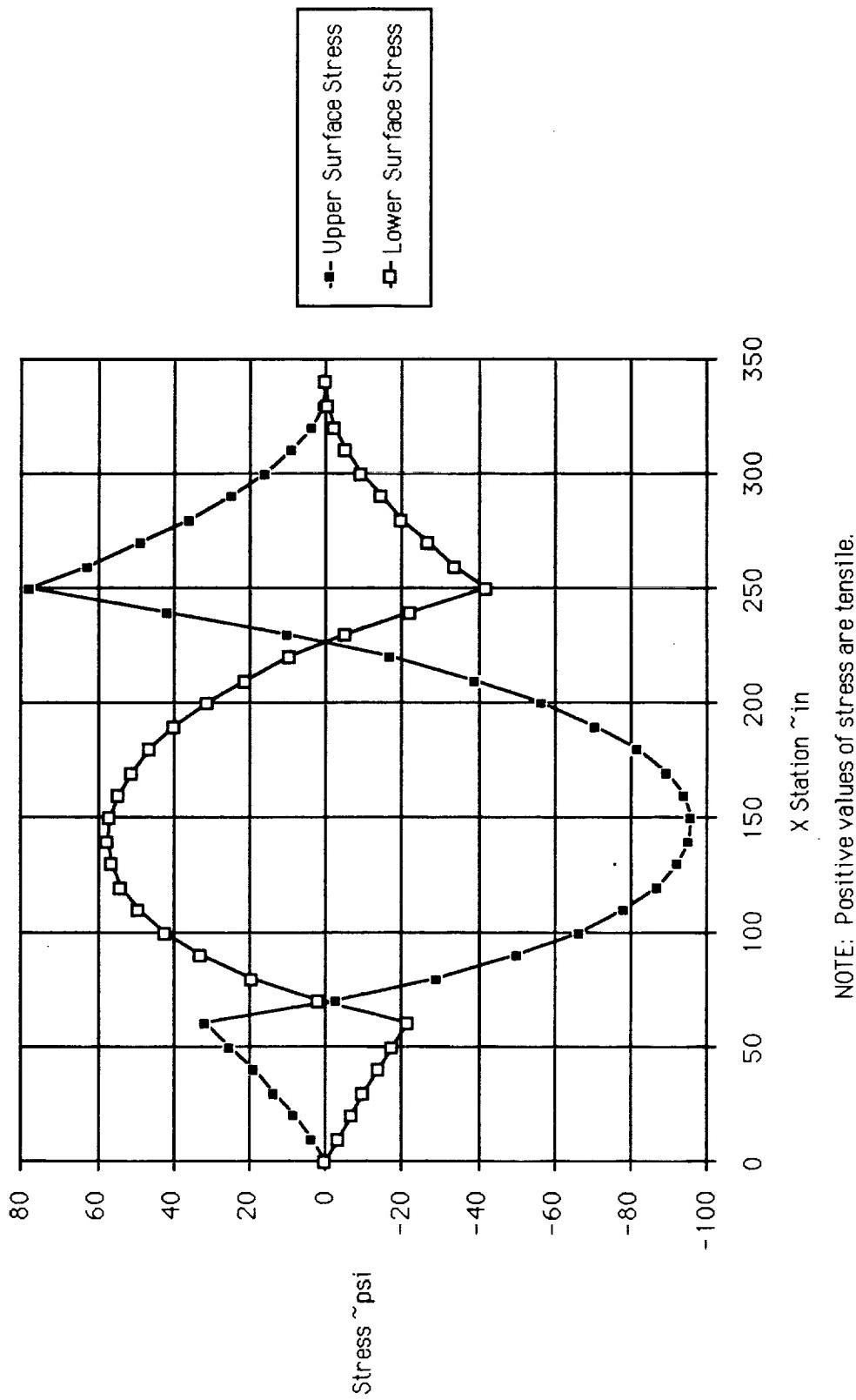
Load Case 1: Total Weight = 7670 lb CG = 173.4





PLS Mockup Vertical Bending Stress

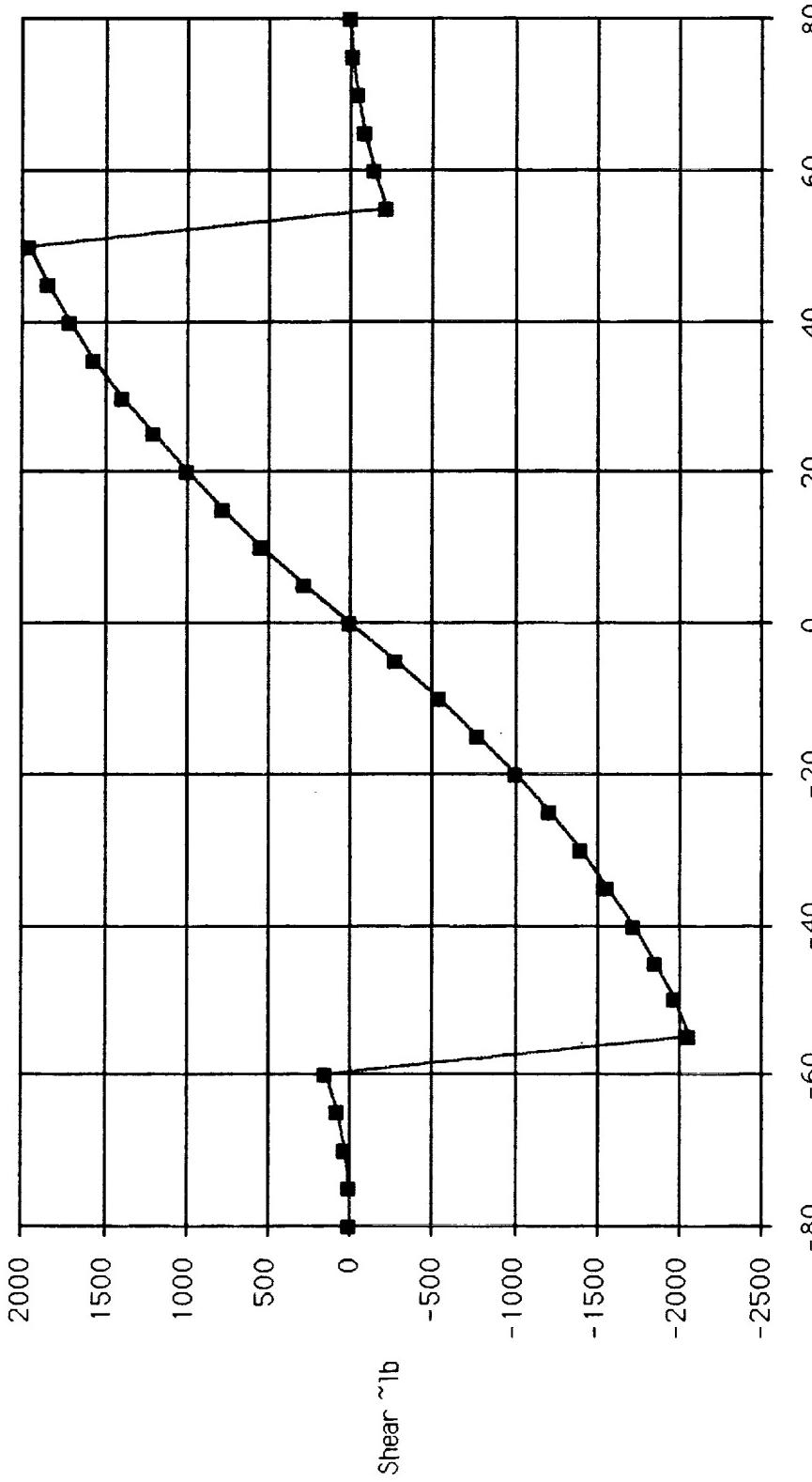
Load Case 1: Total Weight = 7670 lb CG = 173.4



NOTE: Positive values of stress are tensile.
X Station ~ in

PLS Mockup Lateral Shear Load

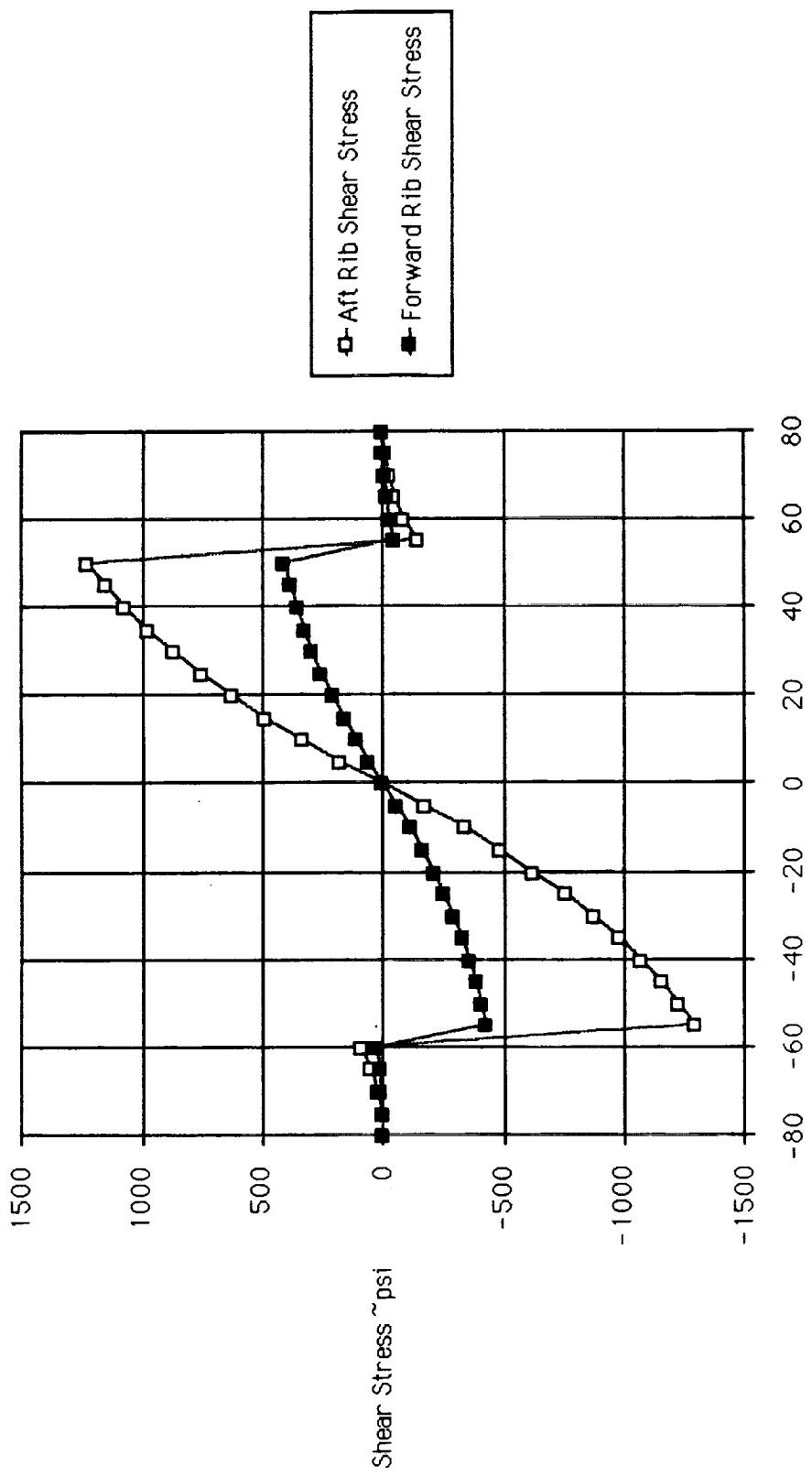
Load Case 1: Total Weight = 7670 lb CG = 173.4



NOTE: Assumes triangular load distribution.
Y Station ~in

PLS Mockup Lateral Shear Stress

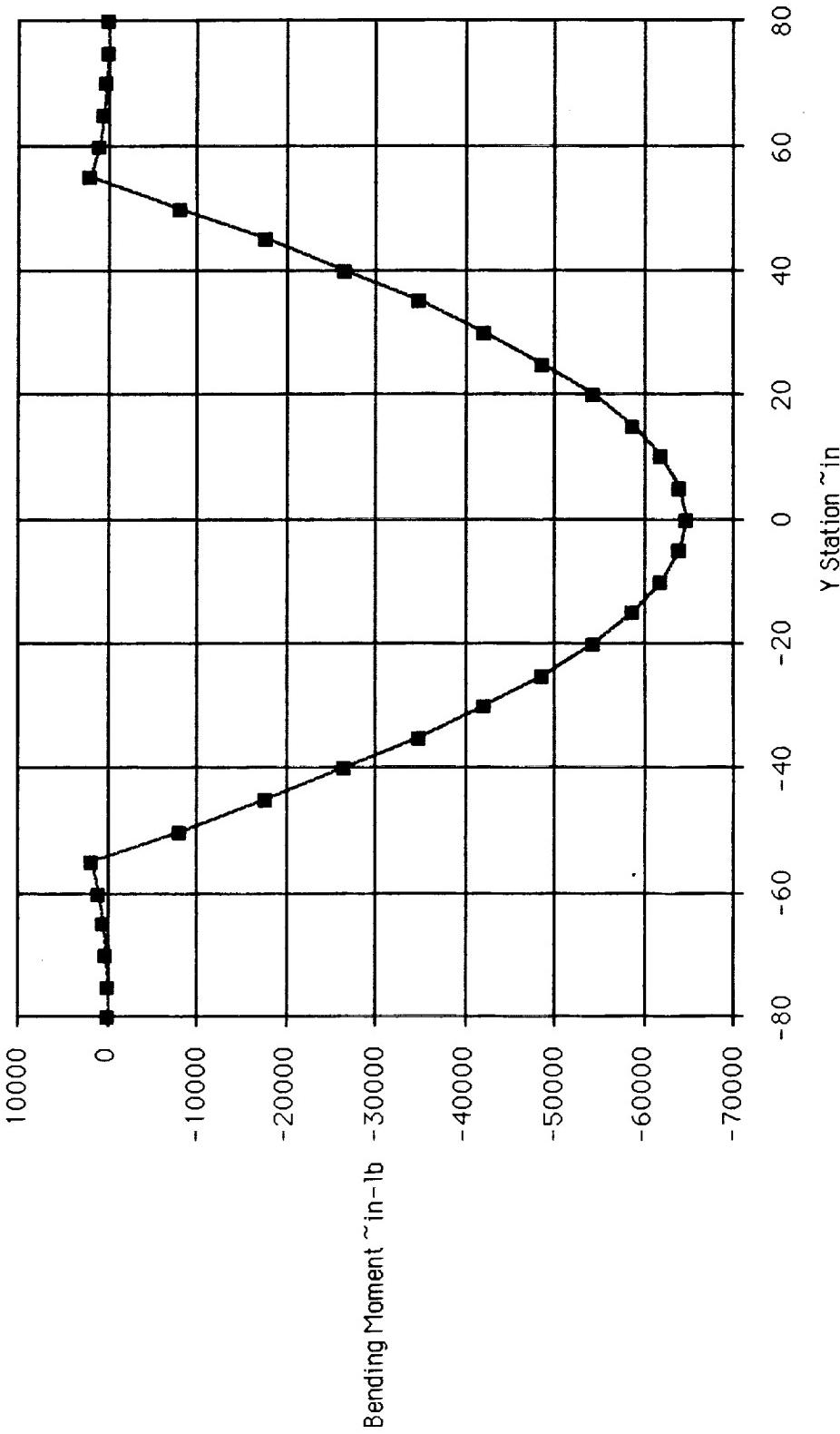
Load Case 1: Total Weight = 7670 lb CG = 173.4



NOTE: Aft spar carries 75% of main gear lateral load.

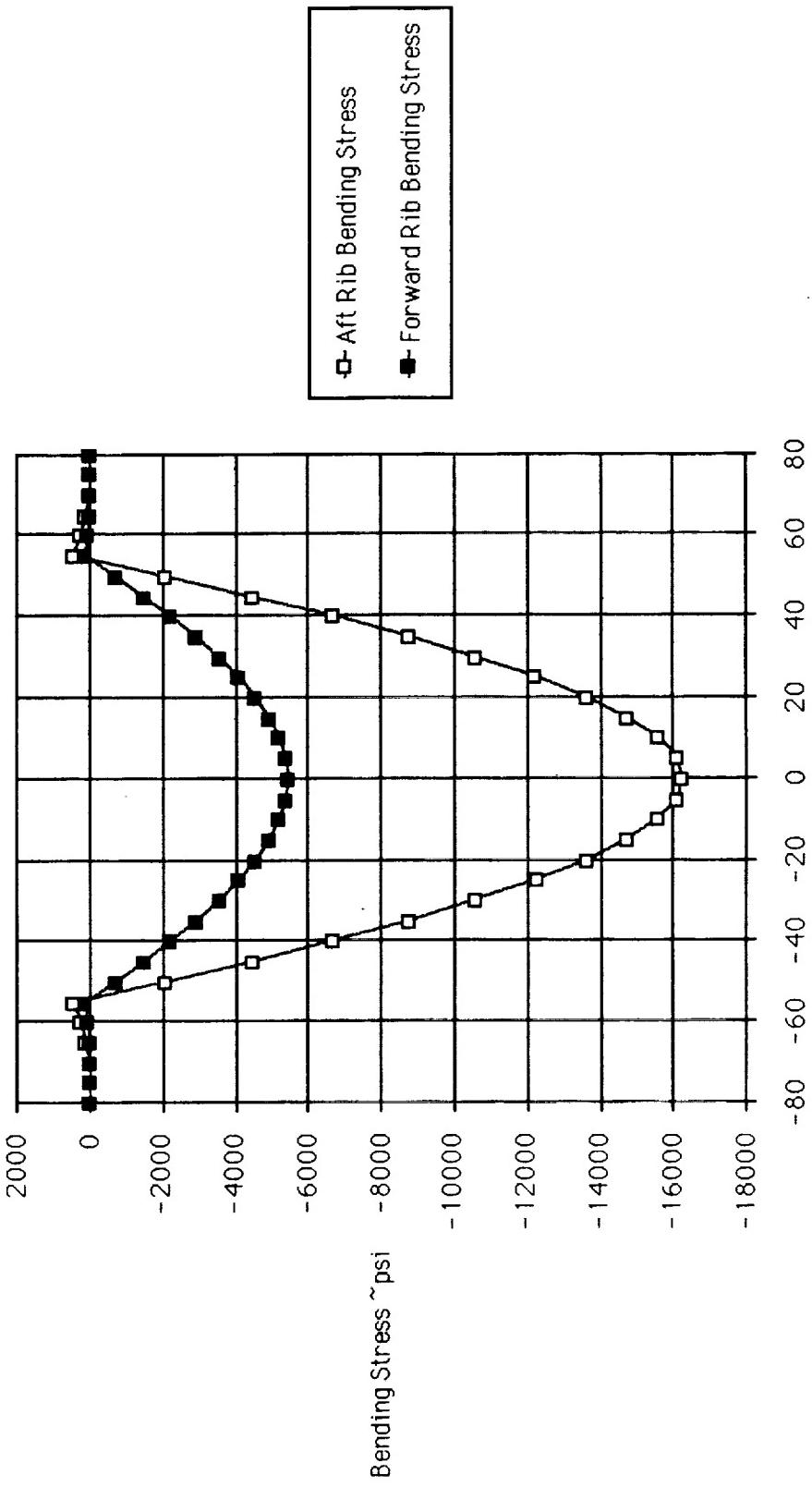
PLS Mockup Lateral Bending Moment

Load Case 1: Total Weight = 7670 lb CG = 173.4



PLS Mockup Lateral Rib Bending Stress

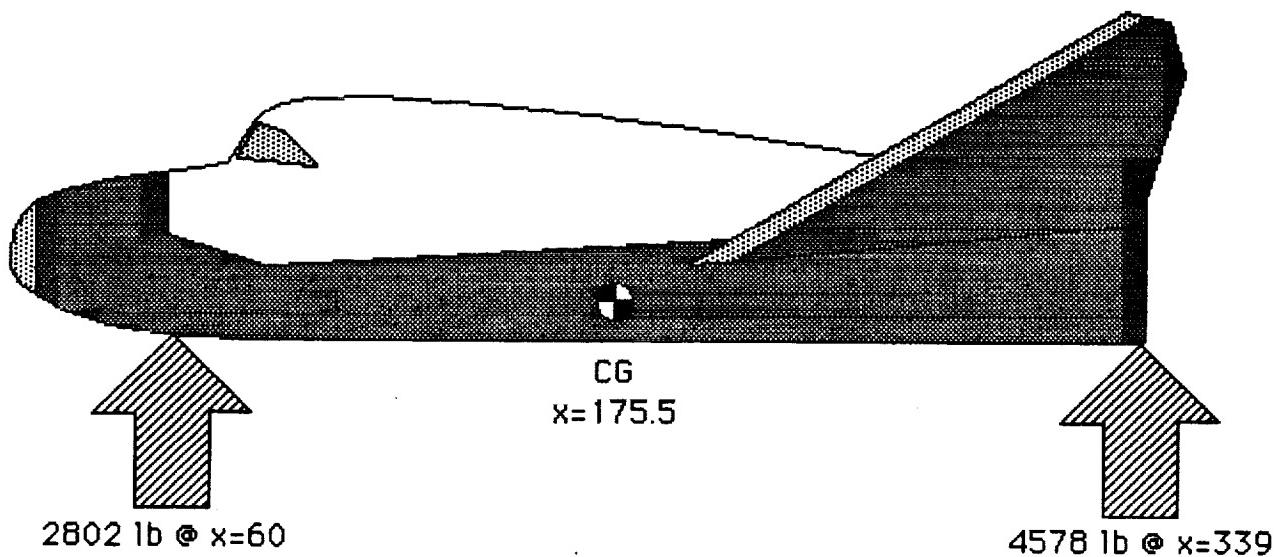
Load Case 1: Total Weight = 7670 lb CG = 173.4



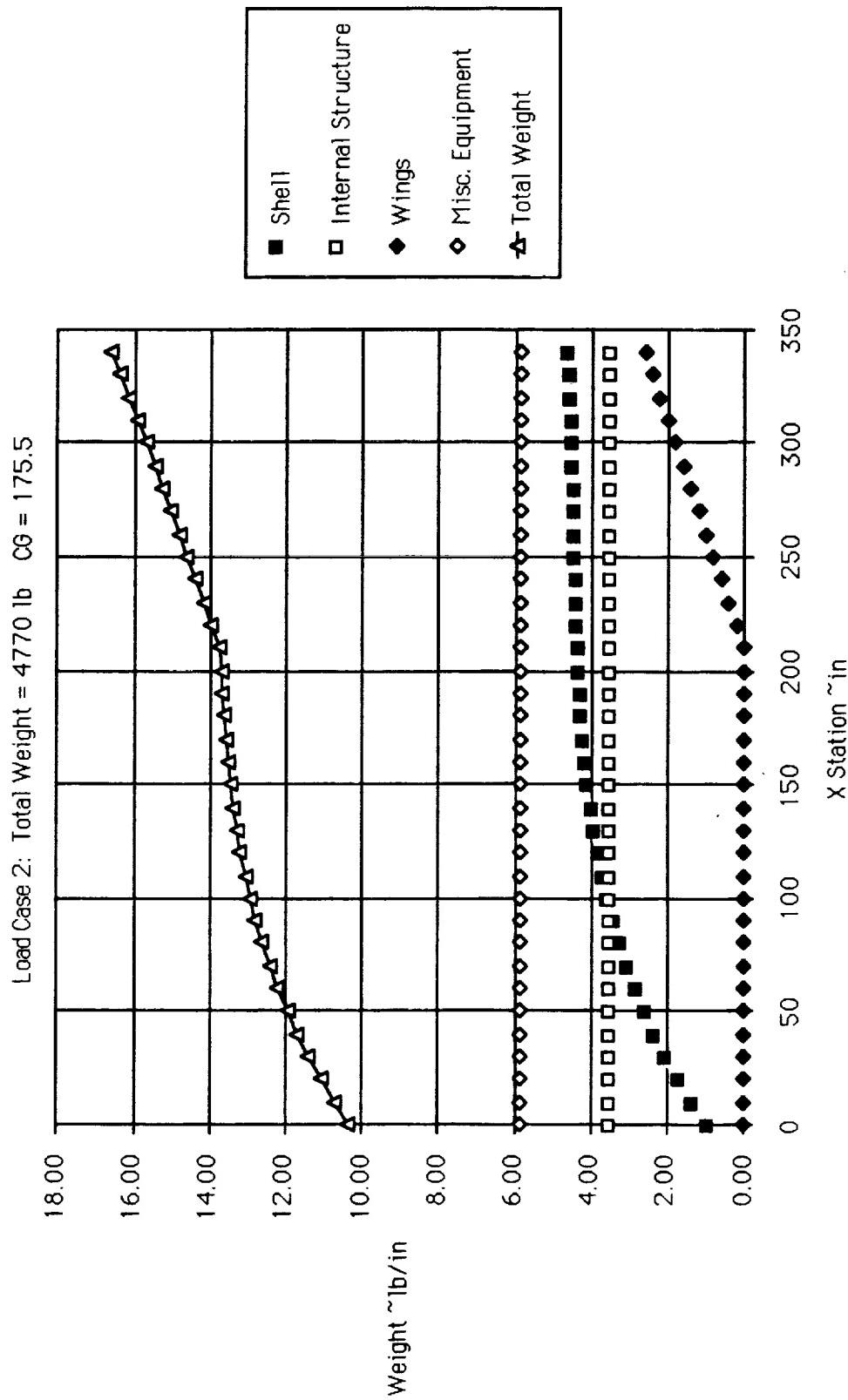
NOTE: Aft rib carries 75% of main gear lateral load.

Load Case 2

Vehicle loaded with equipment only. Weight is 4770 lb. This case represents the initial load encountered when vehicle is hoisted to the vertical position and is the worst case for longitudinal bending.

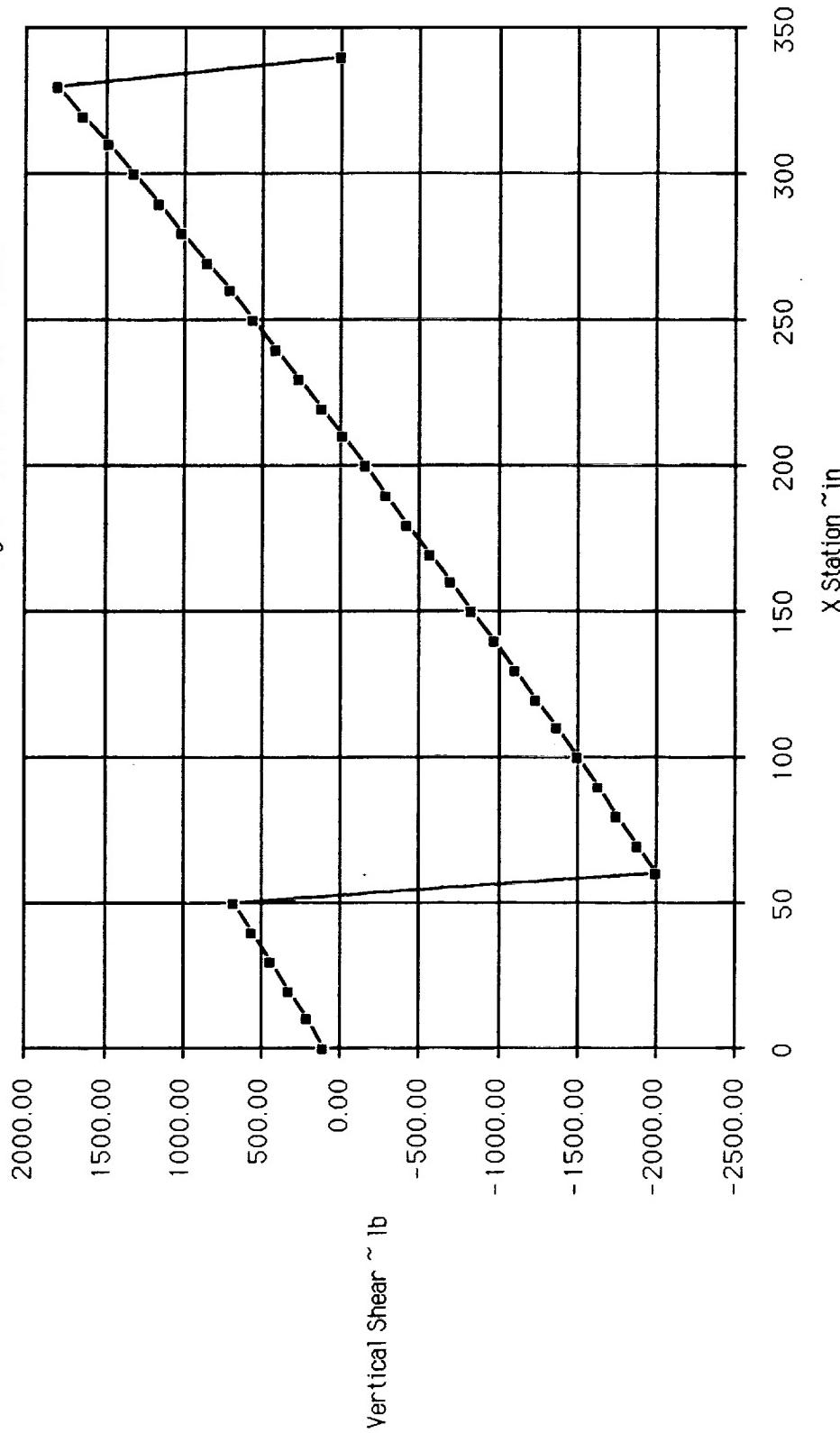


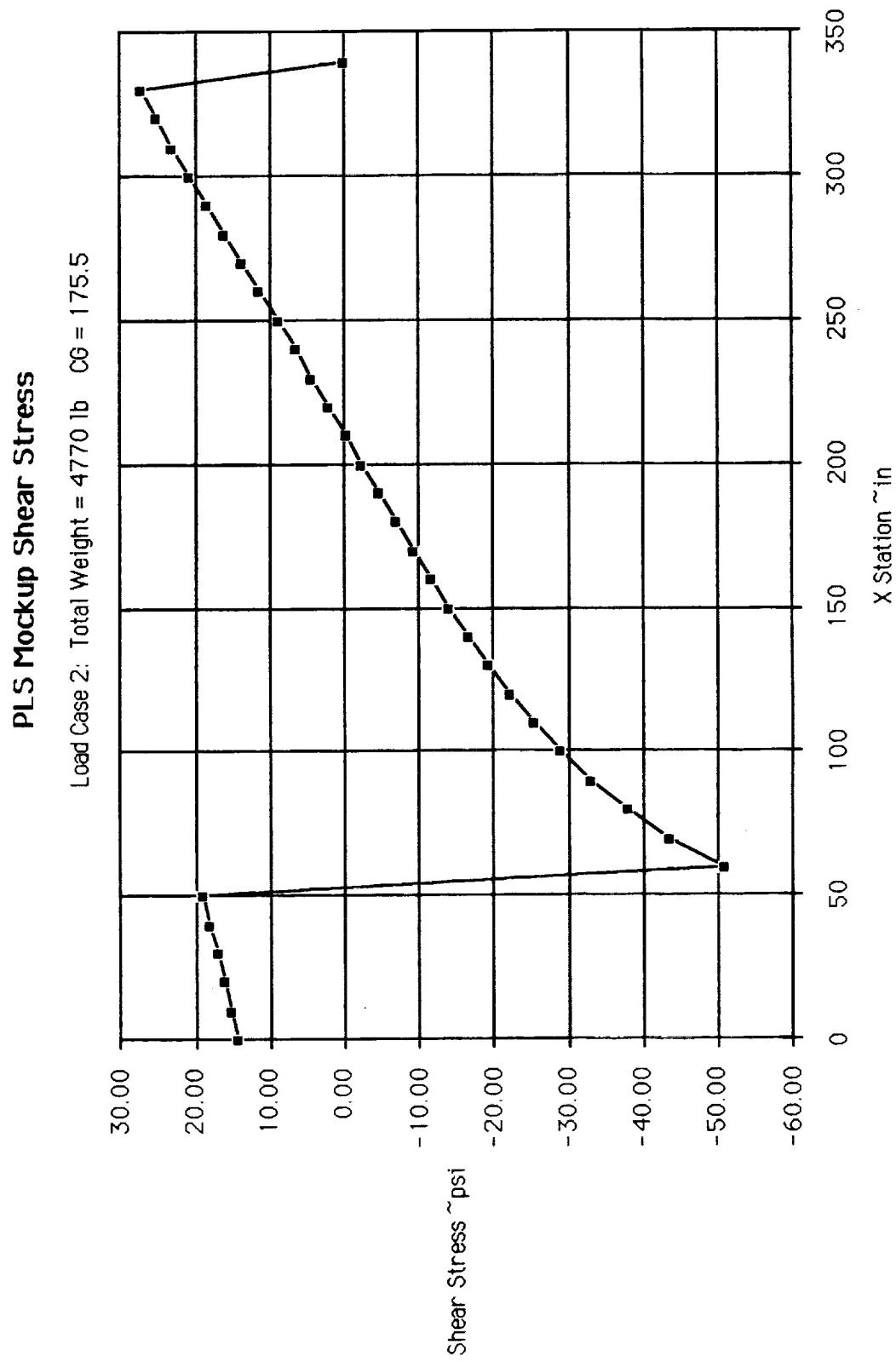
PLS Mockup Weight Distribution

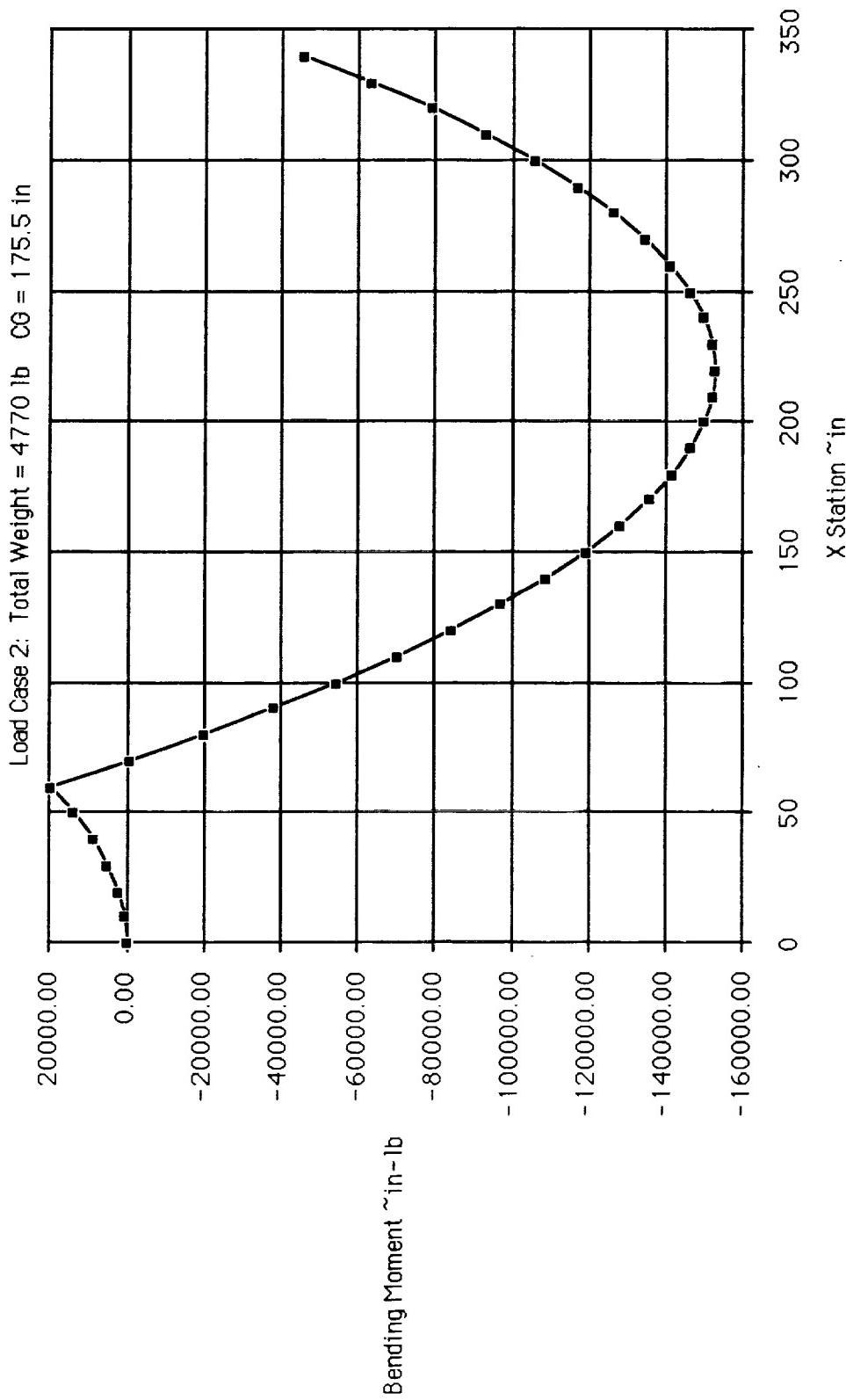


PLS Mockup Vertical Shear Load

Load Case 2: Total Weight = 4770 lb CG = 175.5

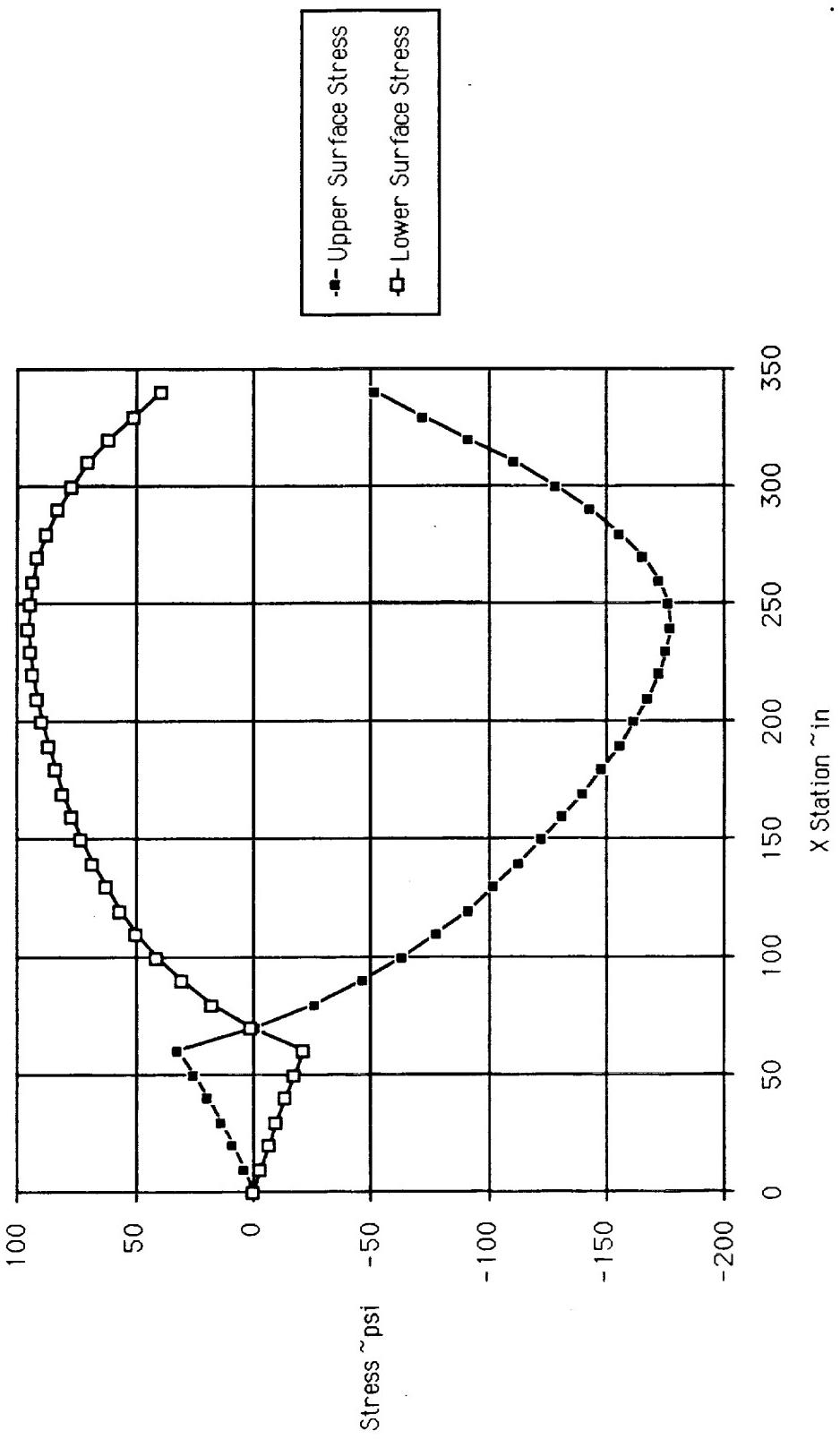




PLS Mockup Vertical Bending Moment

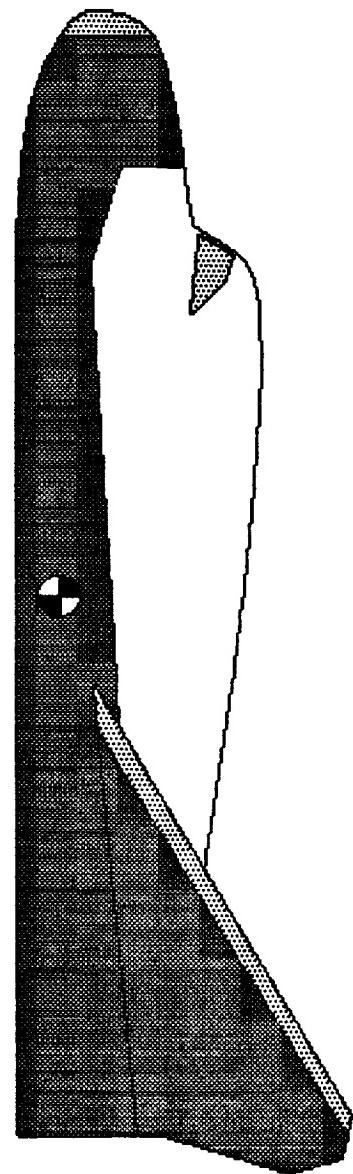
PLS Mockup Vertical Bending Stress

Load Case 2: Total Weight = 4770 lb CG = 175.5



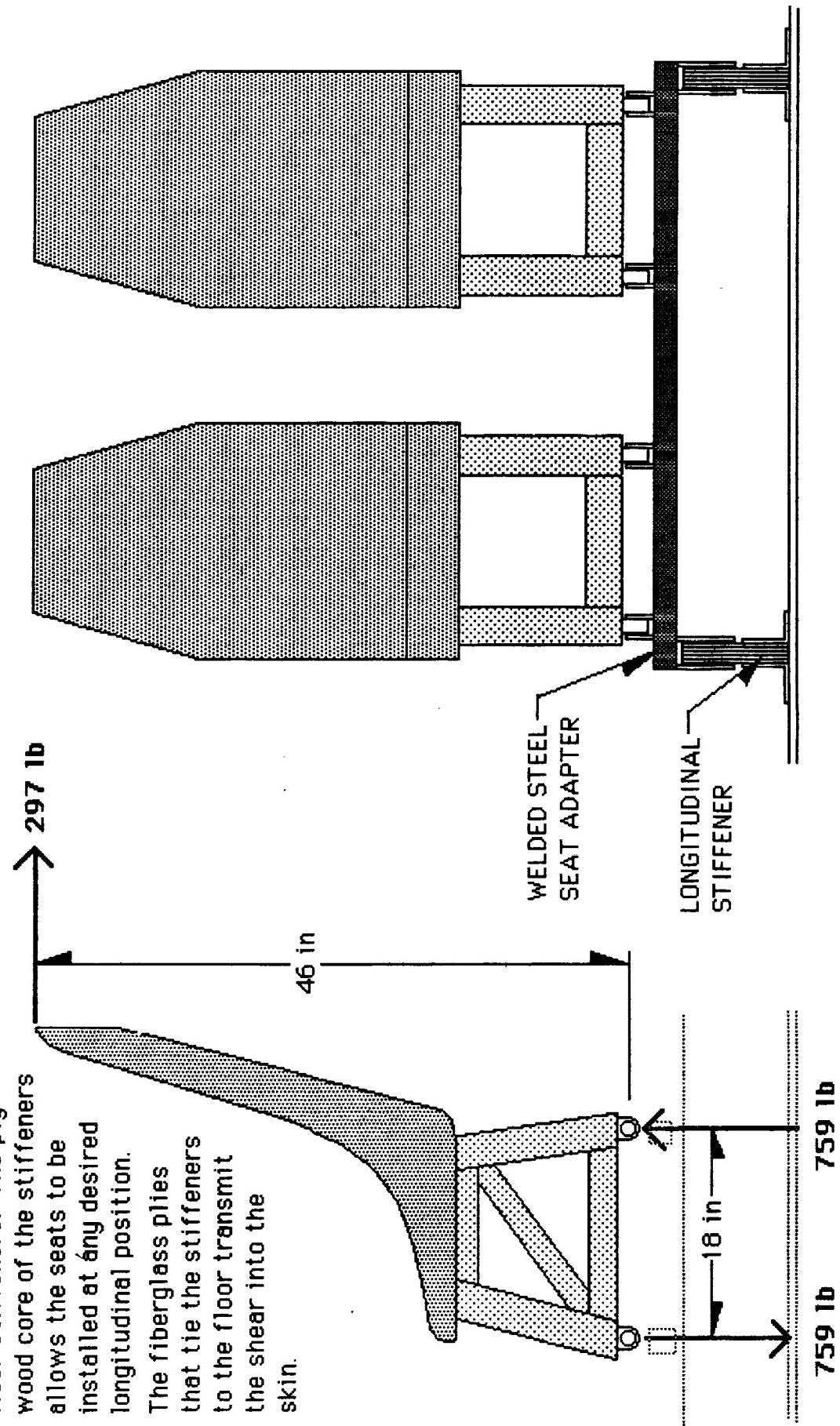
Load Case 3

The vehicle is in the vertical position and is at maximum gross weight (7670 lb as in case 1). The loads imposed upon the overall structure in this case are easily handled by the skins in compression (~120 psi average compression near aft end). The highest loads in this case are the local bearing and bending loads at each of the seat mounts.



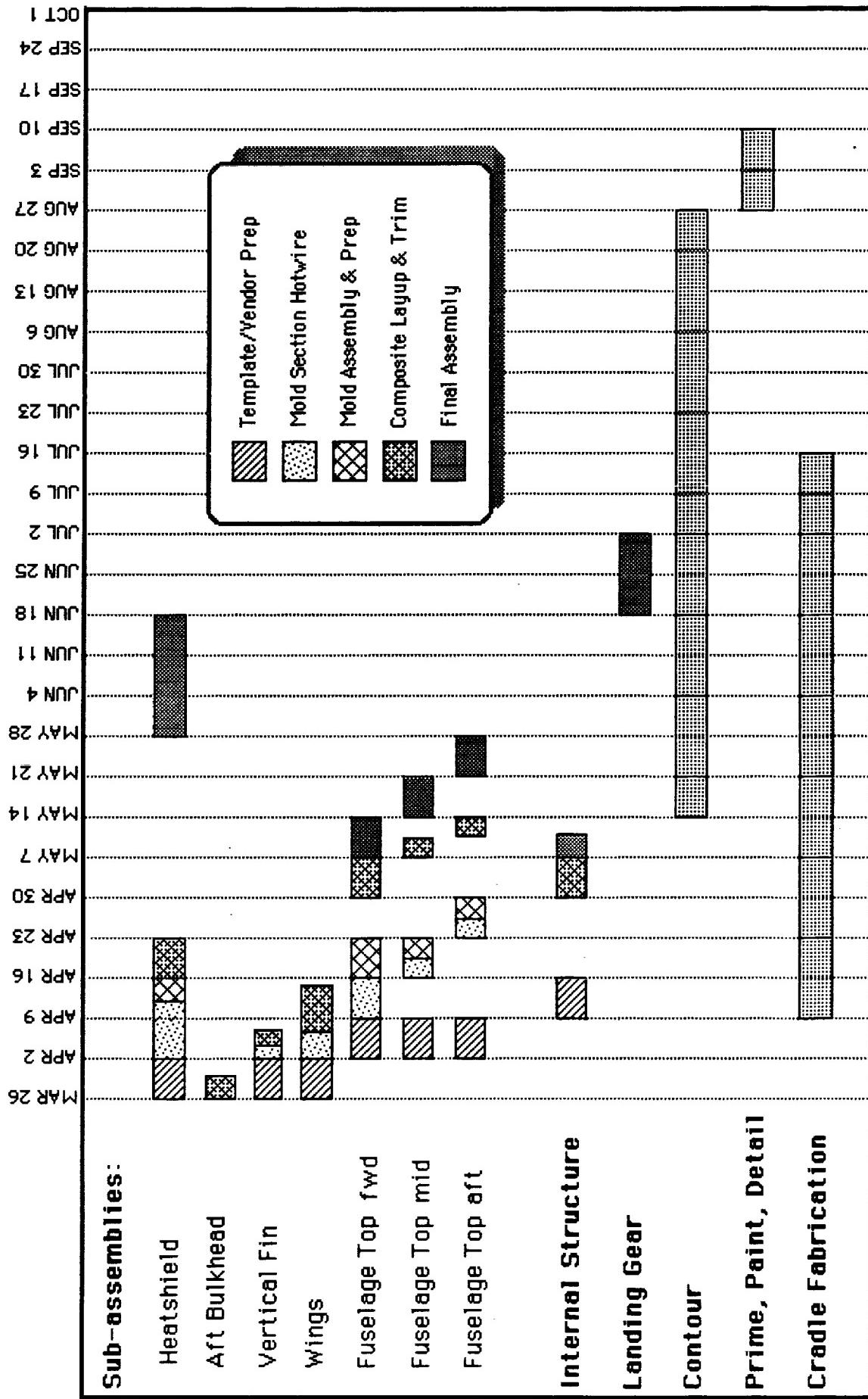
Seat Attachment:

Each pair of seats is attached to two steel adapters that bolt to the longitudinal floor stiffeners. The plywood core of the stiffeners allows the seats to be installed at any desired longitudinal position. The fiberglass plies that tie the stiffeners to the floor transmit the shear into the skin.

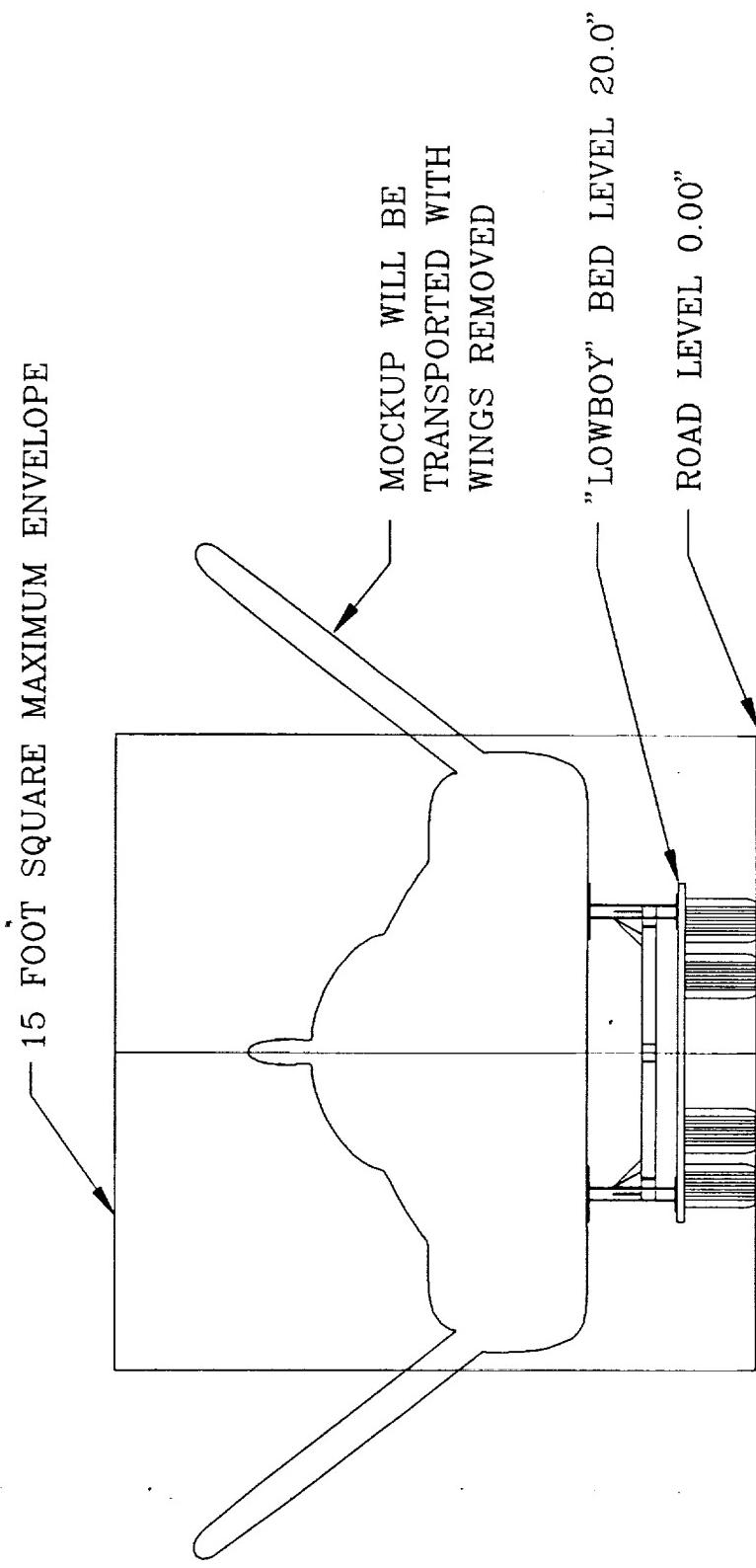


PLS Mockup – Fabrication Schedule

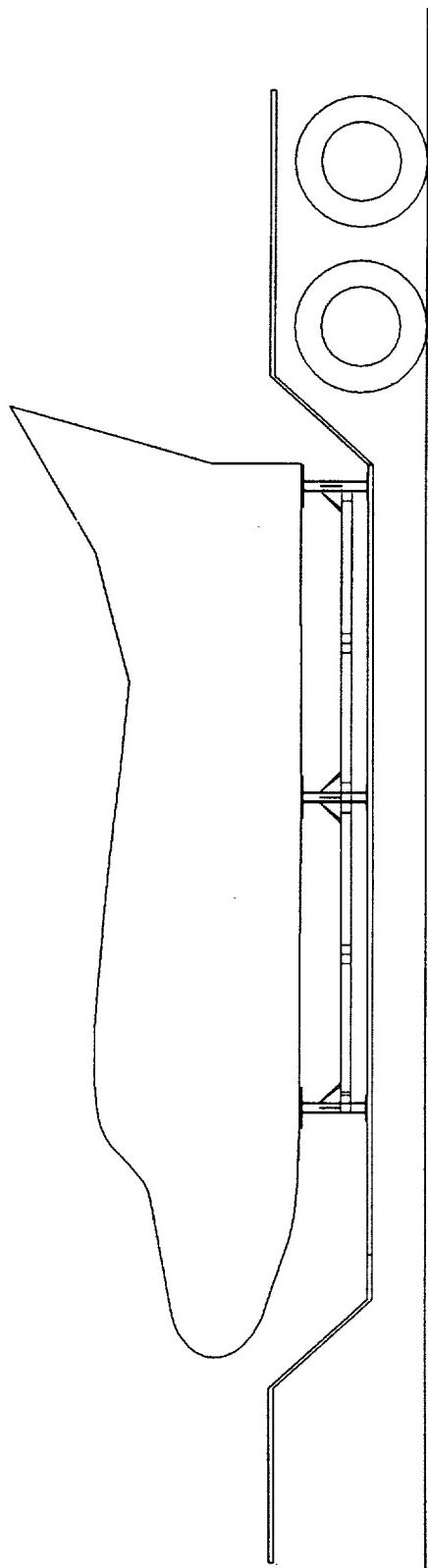
95



PLS TRANSPORTATION CRADLE
END VIEW



PLS TRANSPORTATION CRADLE
SIDE VIEW

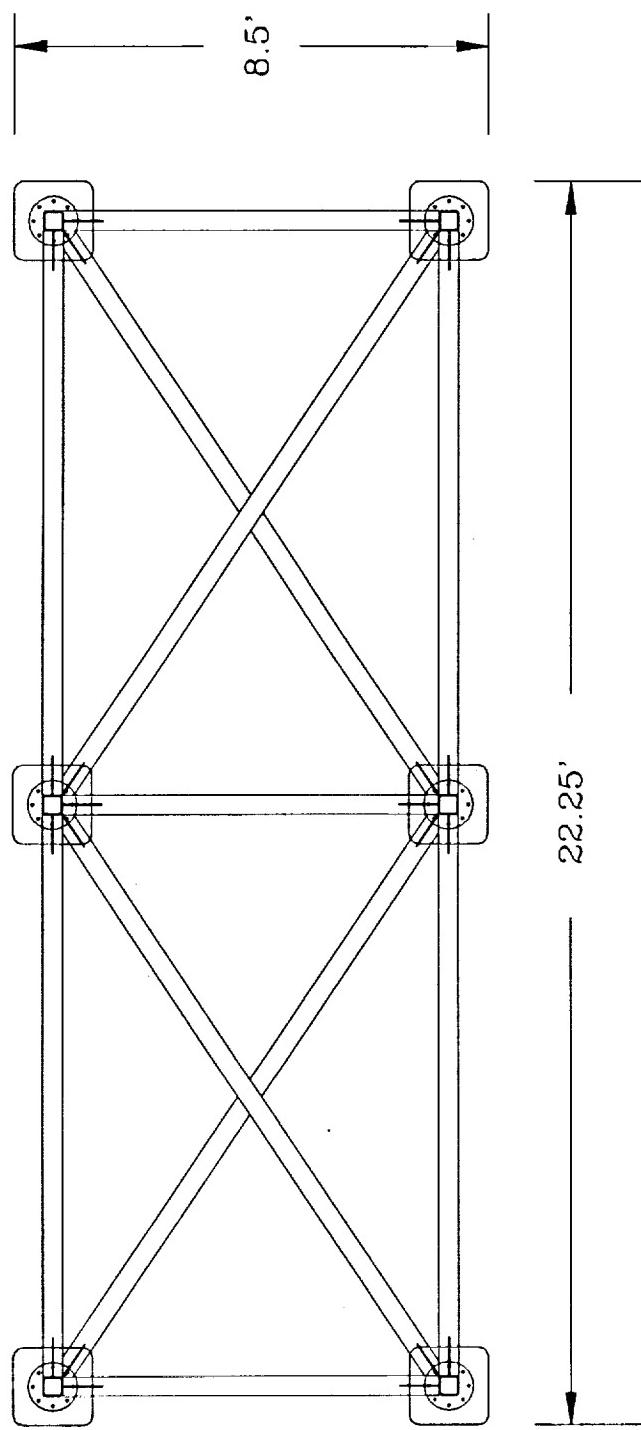


WING STORAGE BELOW FUSELAGE ON CRADLE
PROVISION FOR FORKLIFT BLADE GUIDES
PROVISION FOR CHAIN/STRAP LASHING POINTS

LAYOUT OF OVER THE ROAD TRANSPORTATION OPTION
26 FOOT BED DOUBLE DROP FLATBED TRAILER

CRADLE STRUCTURE

TOP VIEW



SIMPLE STEEL TRUSS STRUCTURE

ALL WELDED CONSTRUCTION

FULLY GUSSETED BEAM/COLUMN JOINTS
4.0" SQUARE BY 0.25" WALL STRUCTURAL STEEL TUBING
6 18" SQUARE CONFORMAL MOCKUP SUPPORT PADS

6 12" DIAMETER PAD FEET